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OUR BROCHURE No. 473 WHICH PROVIDES A WEALTH OF INFORMATION WILL BE FORWARDED ON REQUEST.

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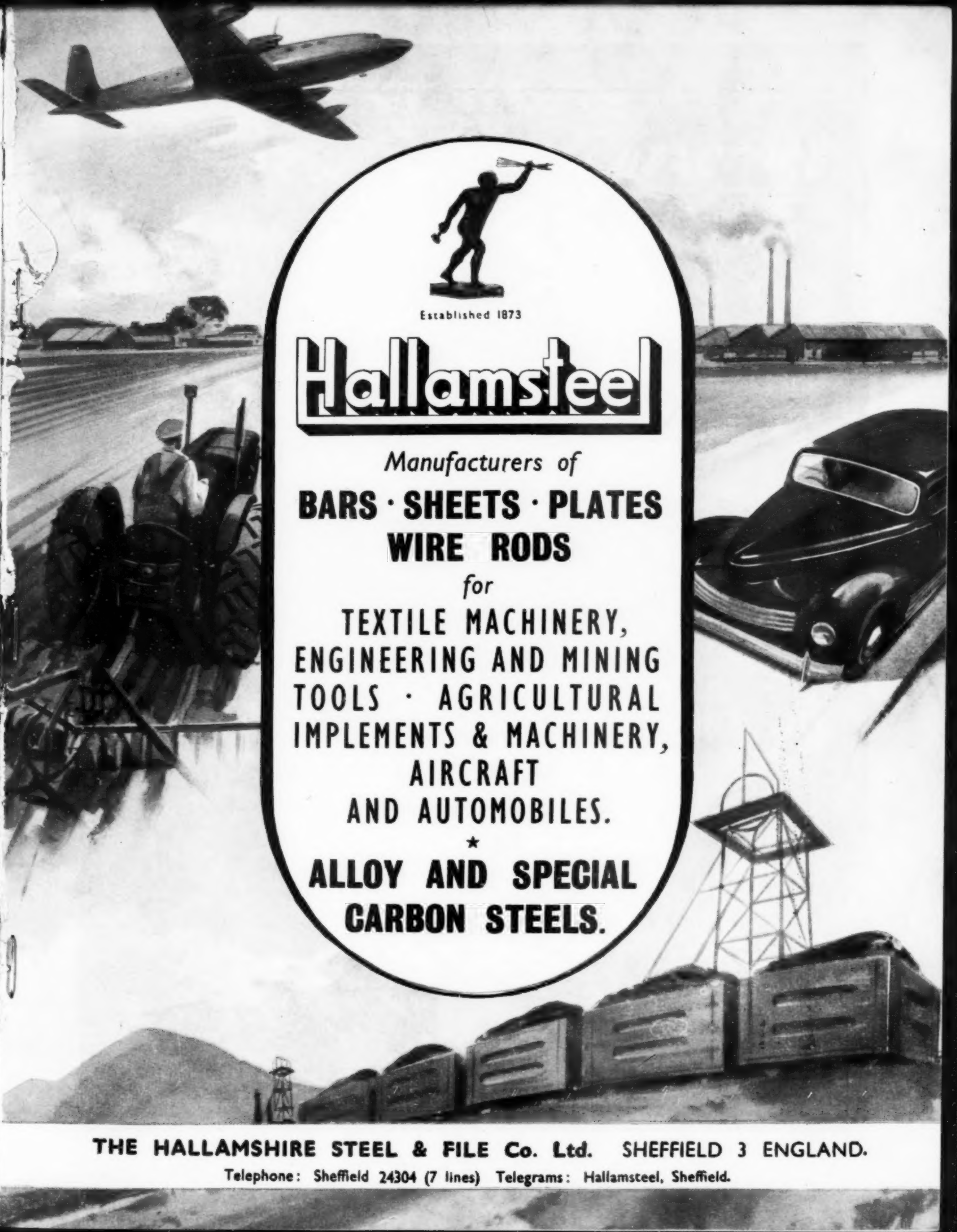

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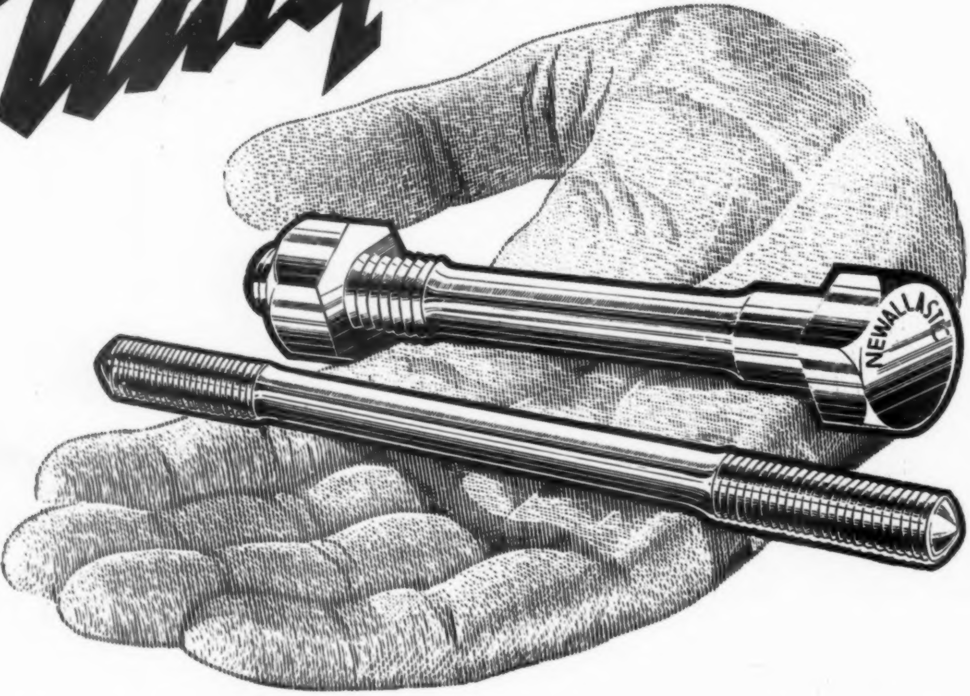

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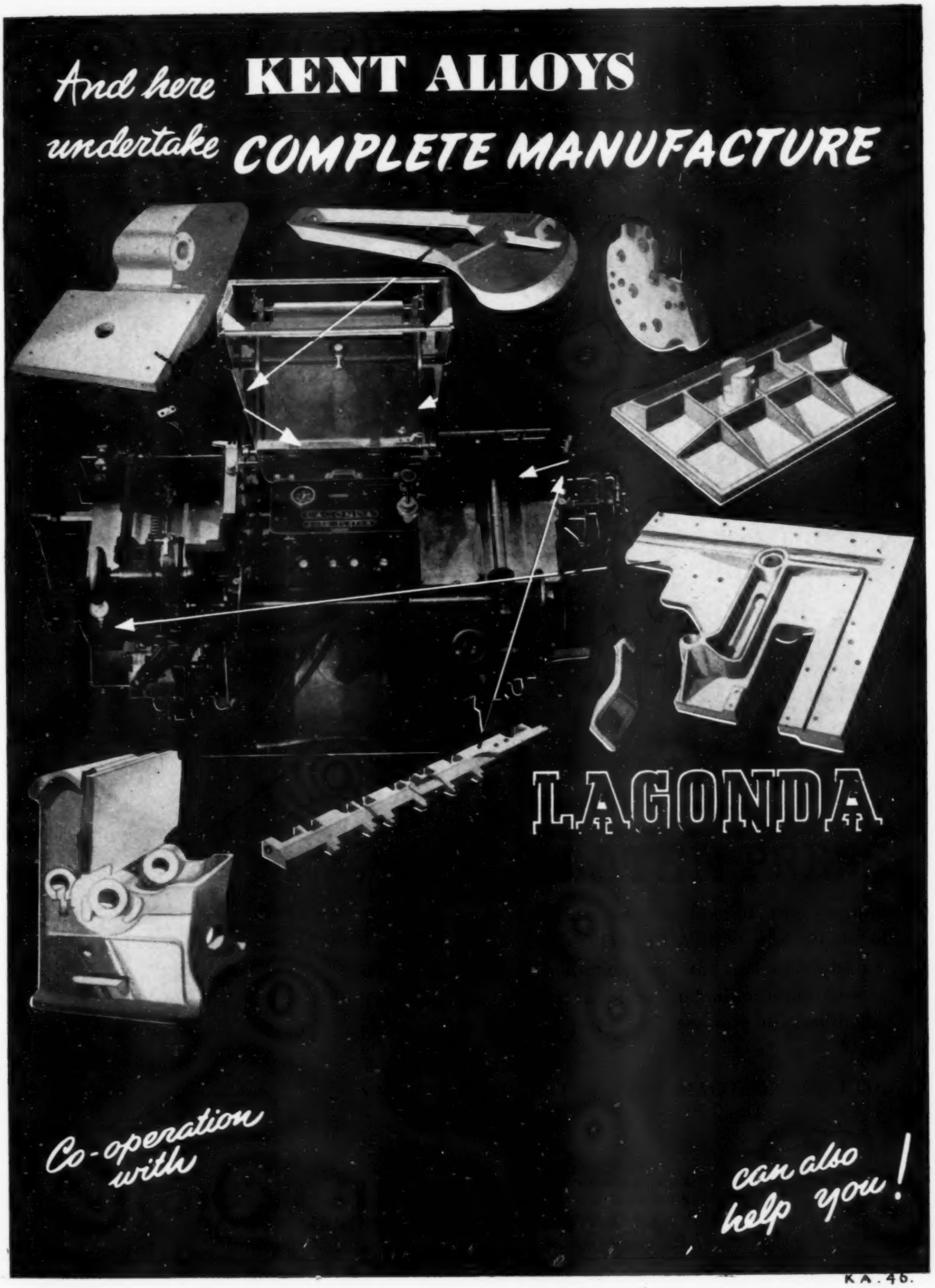
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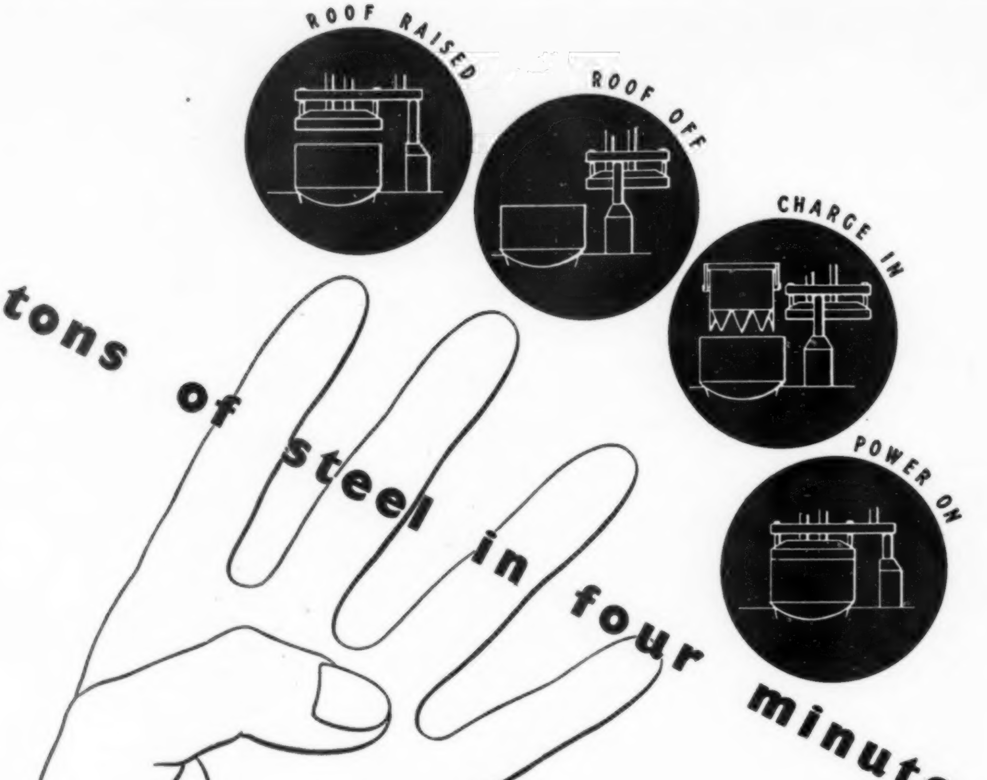
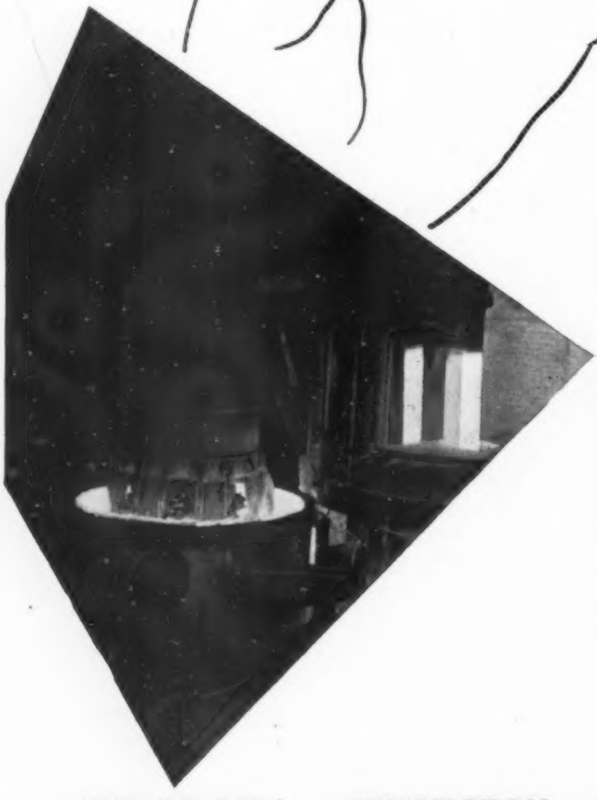
Co-operation with
can also help you!

KA.46.

Ten tons of steel in four minutes





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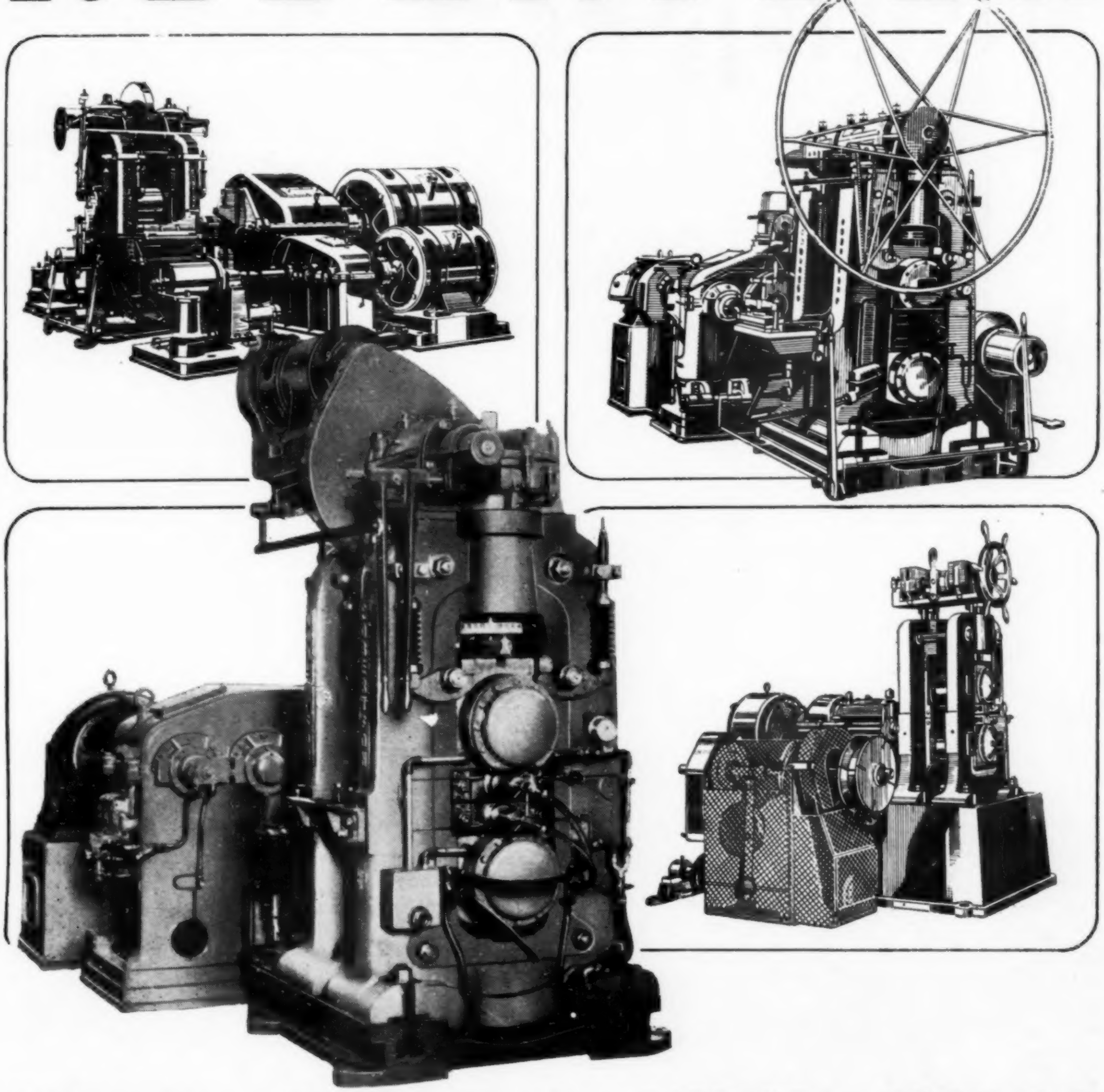

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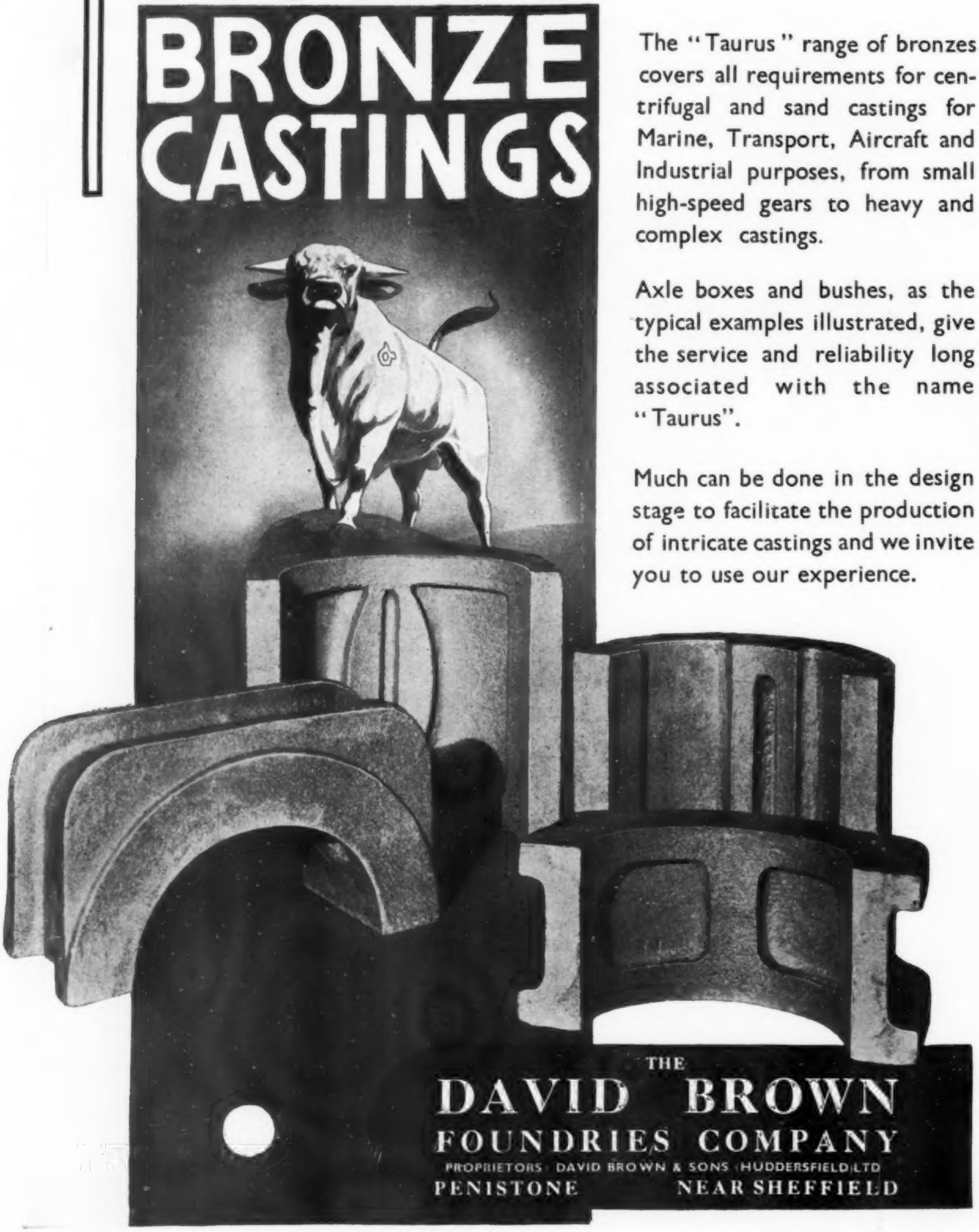

The "Taurus" range of bronzes covers all requirements for centrifugal and sand castings for Marine, Transport, Aircraft and Industrial purposes, from small high-speed gears to heavy and complex castings.

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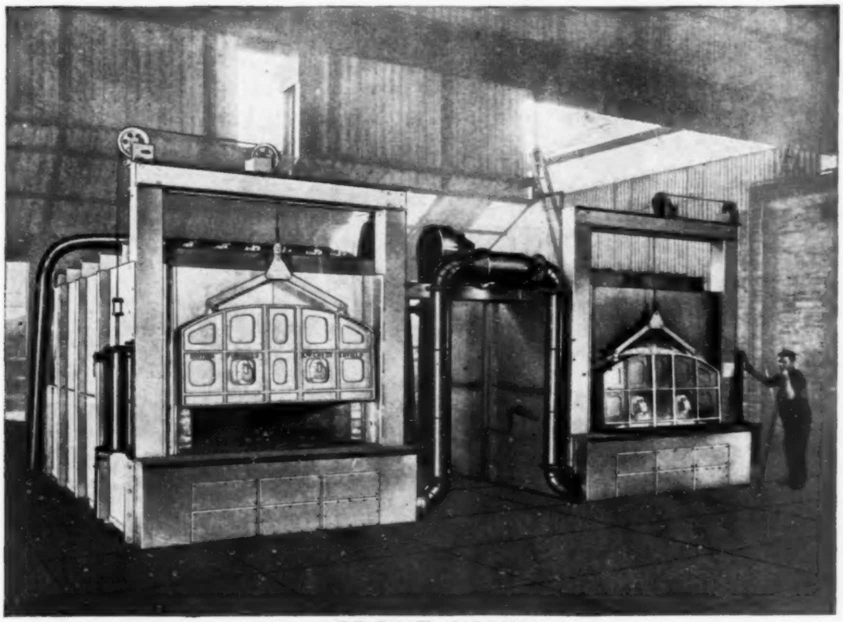

FRONT VIEW

Special Features

- Uniform Slab Temperature
- High Output
- Production of Soft Scale easily removed on first pass
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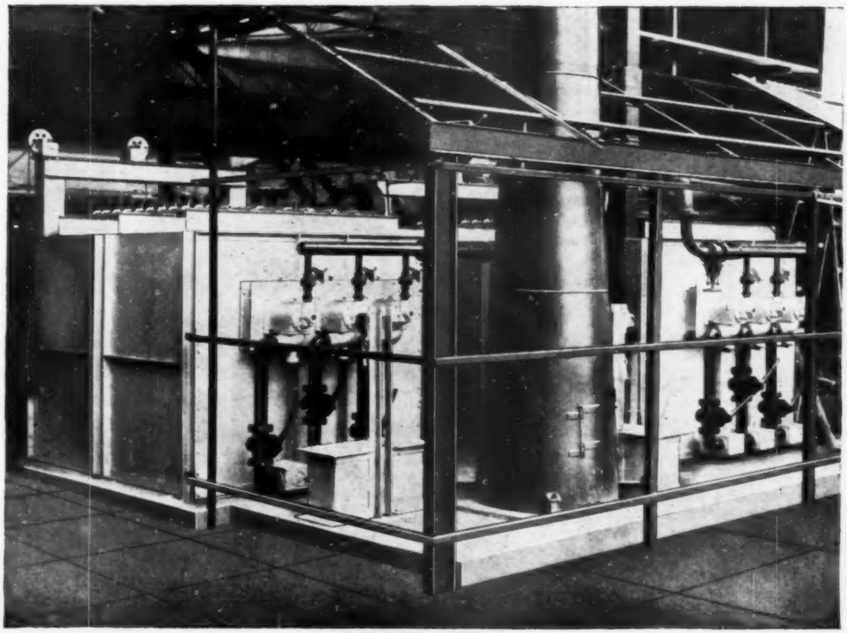
A pair of Sheet Mill Furnaces. Towns Gas Fired, one 6ft. × 6ft. and the other 6ft. × 11ft., either being capable of being used as a "hot" or "slow" fire, *i.e.* 750°C to 1250°C.



REAR VIEW

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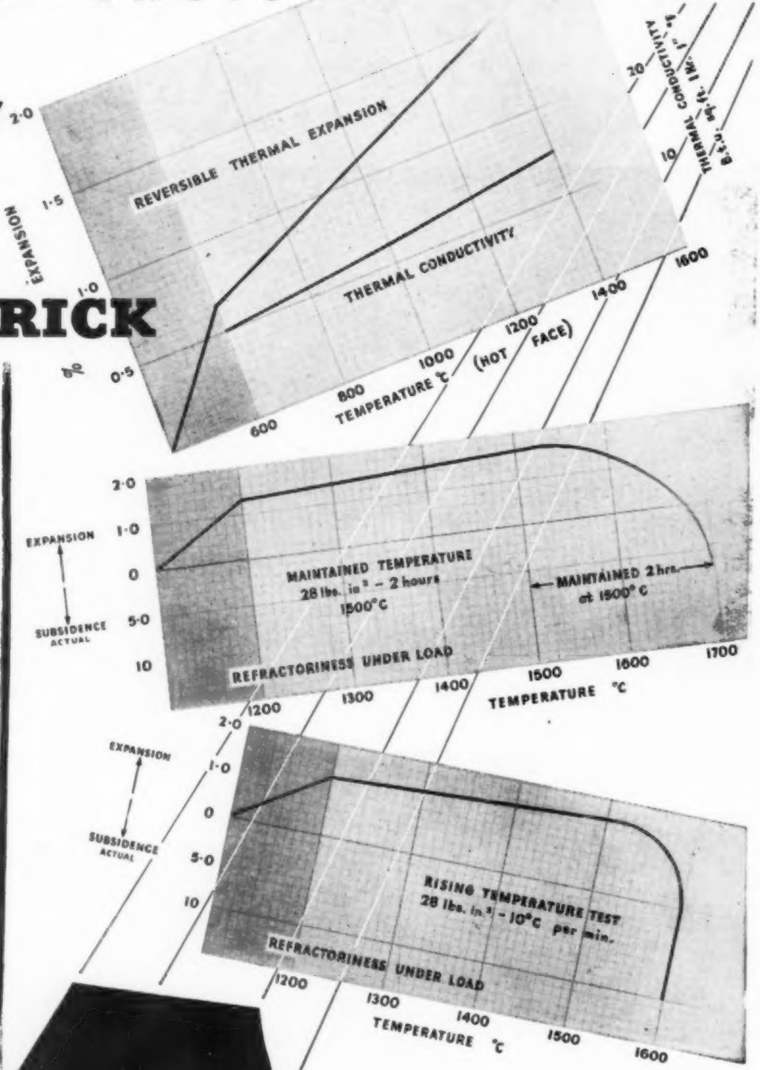
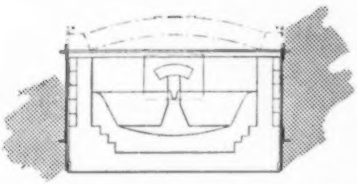
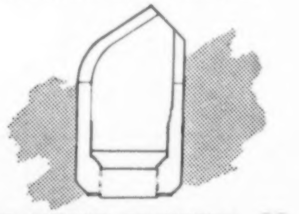
BRITAIN'S BEST BASIC REFRACTORIES

G·R '341' DOLOMITE BRICK

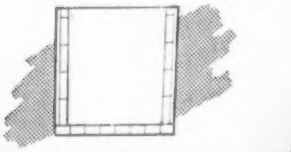




ELECTRIC FURNACES G.R. '341' dolomite bricks are used extensively in walls and bottoms of basic electric arc furnaces. Proved the most economic basic brick available. Complete absence of chromic oxide makes '341' most suited for production of chromium-free alloys. Any size furnace can be lined from standard stock sizes.



BASIC BESSEMER CONVERTERS G.R. '341' bricks, dense and burnt to vitrification at high temperatures are superior to rammed tarred dolomite or 'green' tarred blocks in the lower wall positions. In addition to giving longer and uniform life to the converter the efficiency of the process is greatly improved. Highly resistant to chemical erosion and mechanical attrition.



DESULPHURISING LADLES G.R. '341' bricks provide the perfect lining and solve completely the refractory problems connected with sulphur removal by the sodium-carbonate process. Give a life 8 to 10 times longer than firebrick without patching or attention. A perfect chemical (basic) medium which in addition to longer lining life increases efficiency of process.

The widespread and successful use of the G.R. '341' dolomite brick in Basic Electric Furnaces, Bessemer Converters and Desulphurising Ladles is one of the major achievements in refractories. G.R. '341', the result of many years research and experimentation, is manufactured entirely from British Dolomite and is treated to ensure resistance to atmospheric moisture. Like all G.R. Basic Bricks, '341' is made in one of the most modern plants, embodying all the features of improved brickmaking technique and possessing valuable characteristics developed by years of experience. Full information and advice on the selection and application of refractories will be given on request.

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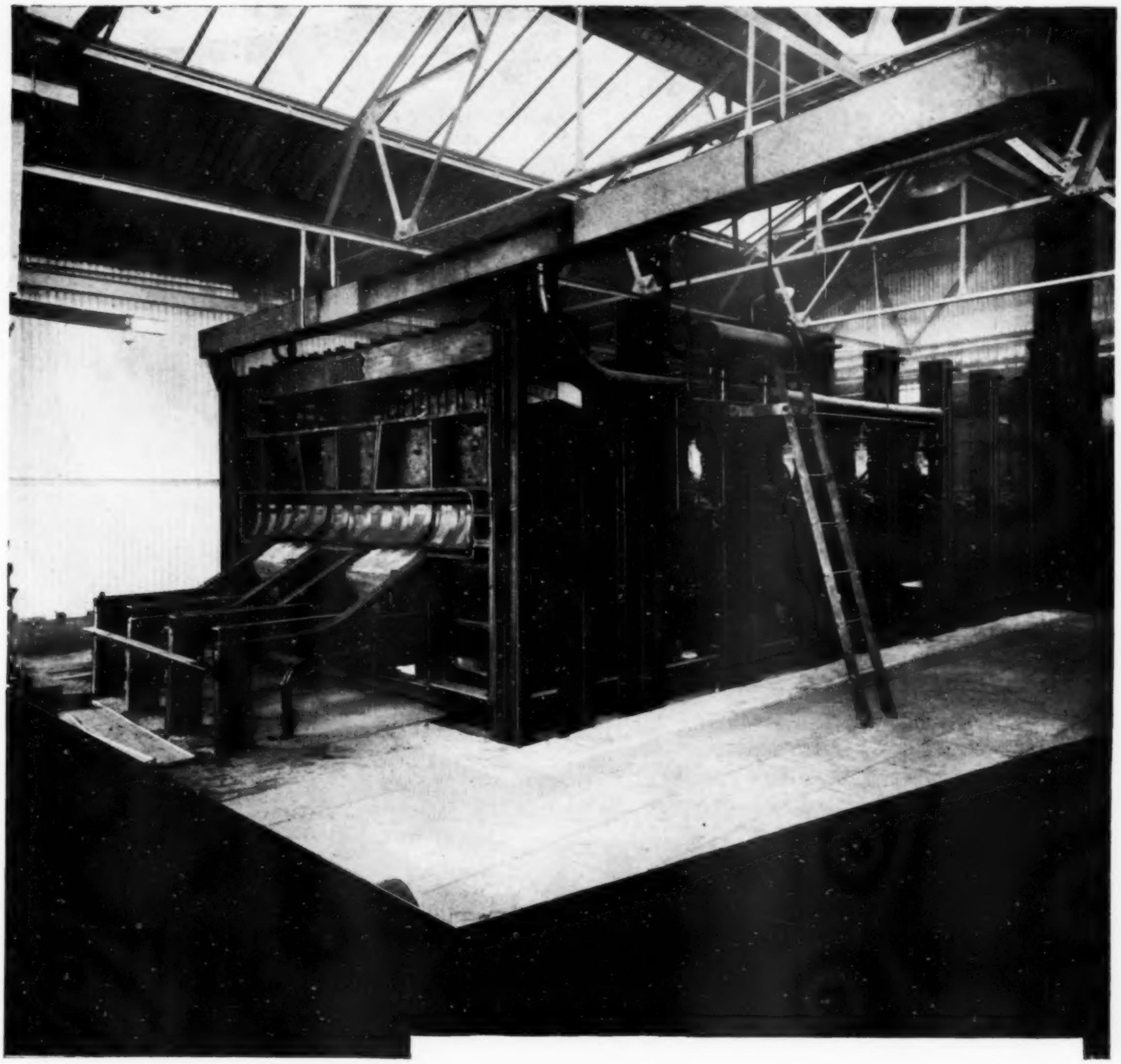

PRIEST

The illustration shows a Walking-Beam Type Oil-Fired Furnace which is used for heating plates for pressing into steel railway sleepers. Capacity 5 tons of plates per hour. One of many Priest specialist designs to suit customers' requirements.

PRIEST FURNACES LIMITED

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F.7

This was the
PROBLEM

21C105
21C105

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Whether or not your casting problems are related to locomotive crankshafts, they can be met by the range of 22 separate types of MEEHANITE metal. The new "Specification of MEEHANITE Metal" booklet has been produced to enable you to select the right type for each particular job. Write for your copy to any of the MEEHANITE Foundries in the list.

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. . . . was established to show Birmal workers how their particular "bits and pieces" fit into the finished article. When men can view the end product which contains the result of their labours they see significance in what otherwise might be, to them, only trivial detail. They learn where and why particular care is necessary and must be exercised. In brief, they are taken into the confidence of the customer and as co-operators they enjoy the responsibility that this entails. Interest and pride in their skill — for much of foundry work is still a craft — grow when they see for themselves the importance of the work of their hands. Again, in the foundry industry we appear to stand rather far back from the export drive but this shop window, full of production goods for "AUSTIN MOTORS," brings home to our workers that we too are considerably involved in redressing the balance of trade between the old world and the new.

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BIRMID WORKS · SMETHWICK · BIRMINGHAM 40

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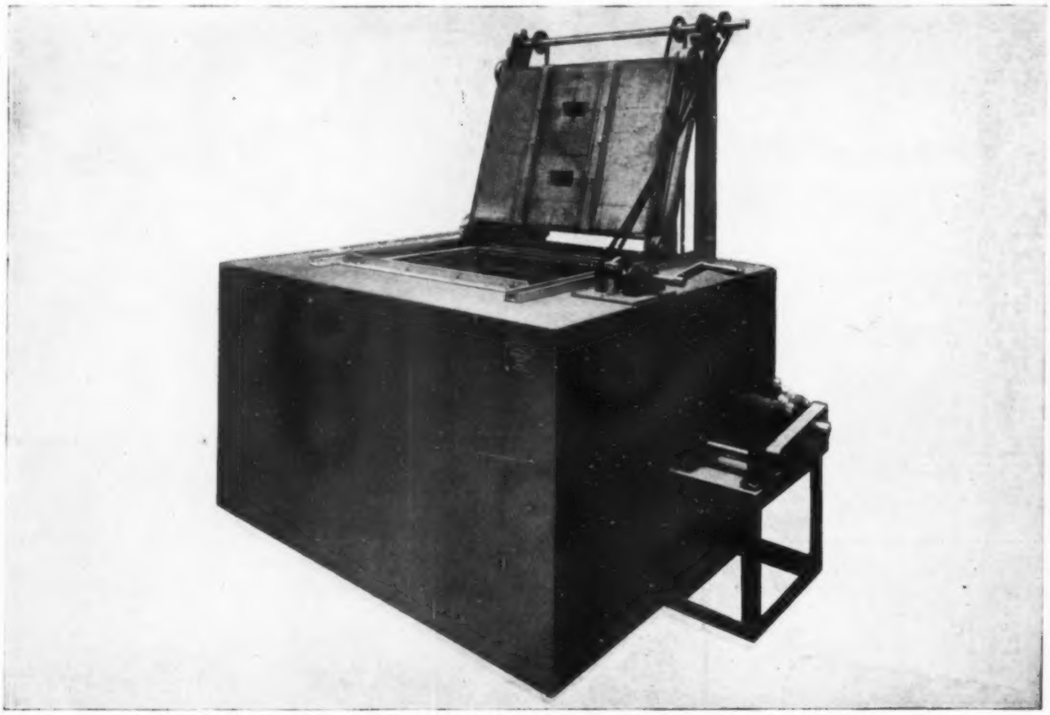
ACCURATE IN ALL THE WORKING SPACE TO ± 5 DEG. C.



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Top Loader Type for Steel Forgings and Pressings

WORK-BASKET 3 ft. × 2 ft. × 2 ft. IN HEAT RESISTING STEEL

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NORMALISING 900° C.—
TEMPERING STEELS—
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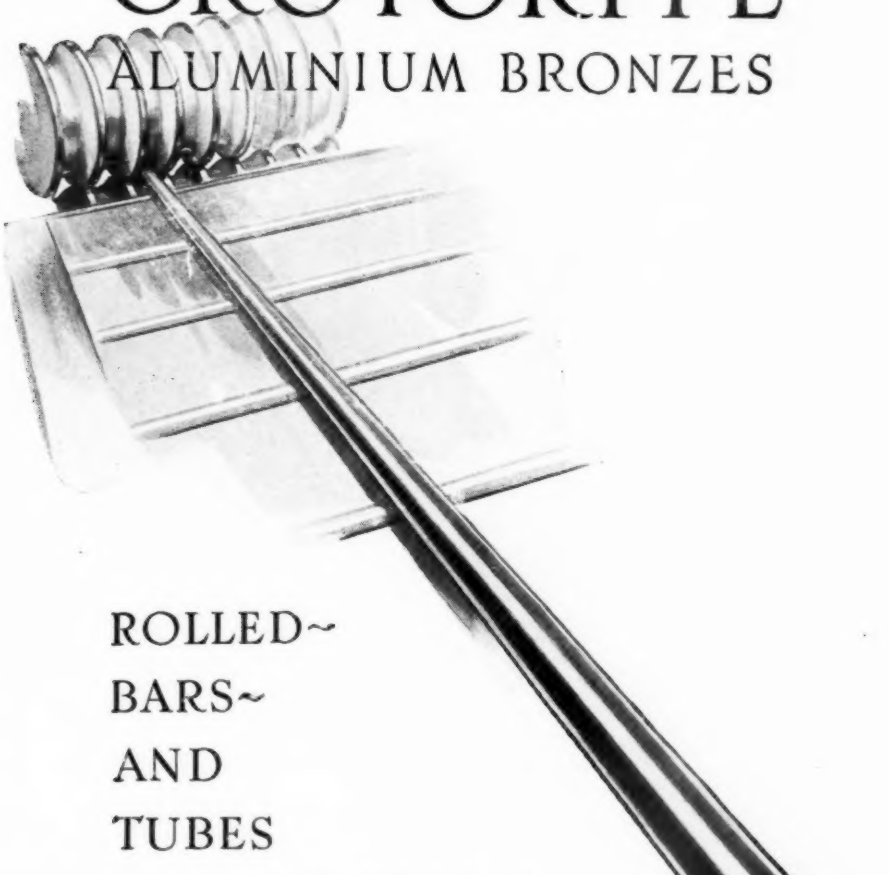

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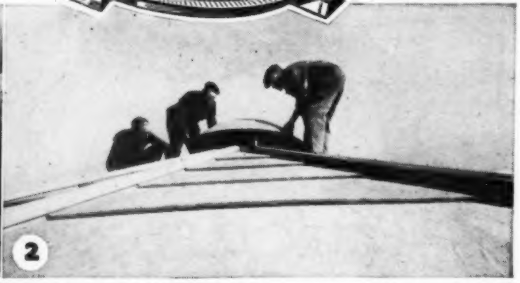
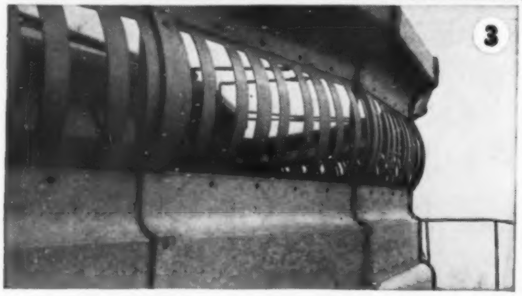
for another instance of the versatility of aluminium. In reconstructing the domed ceiling and parts of the roof, 36½ tons of I.C.I. aluminium alloys are being used.





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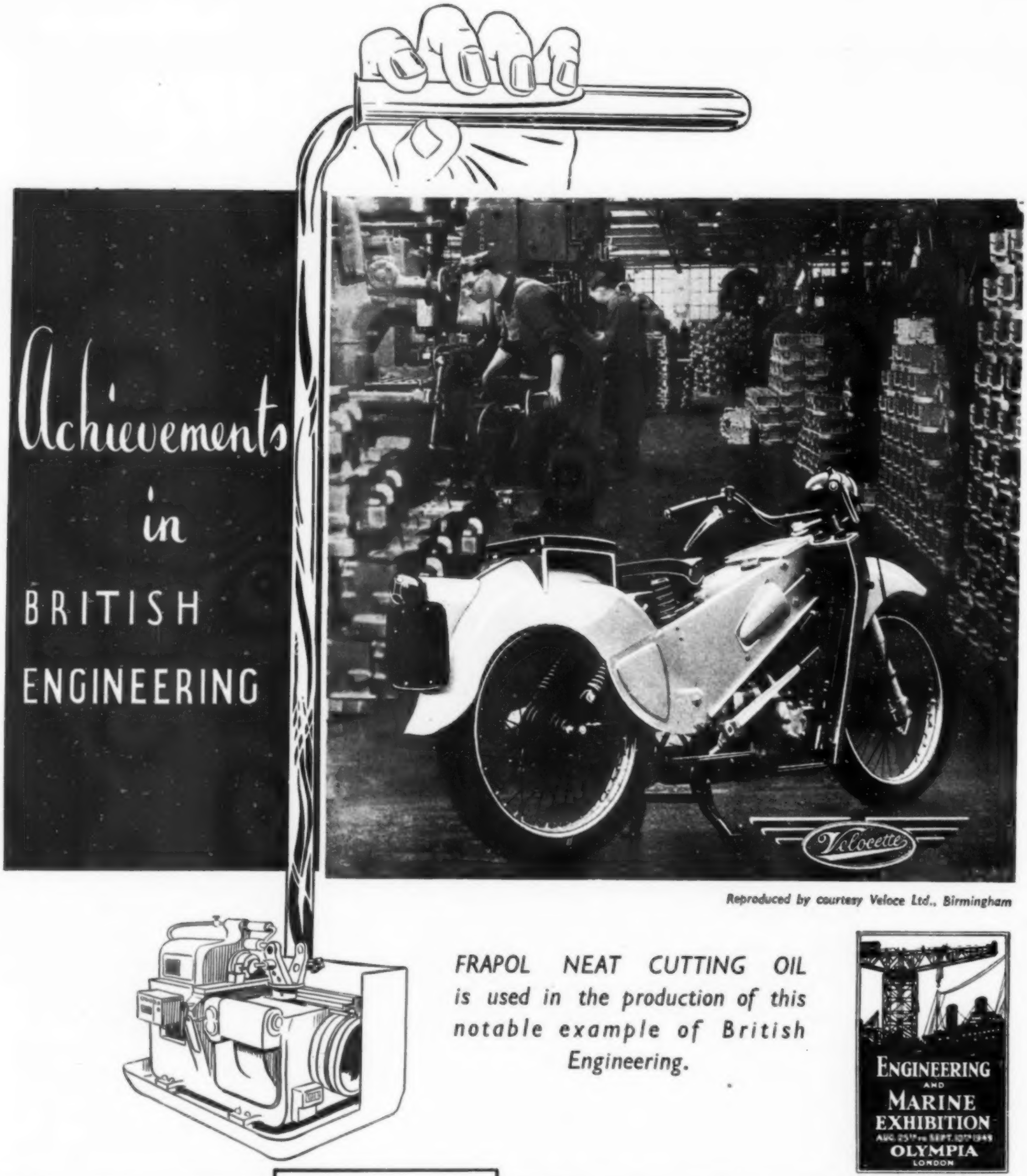
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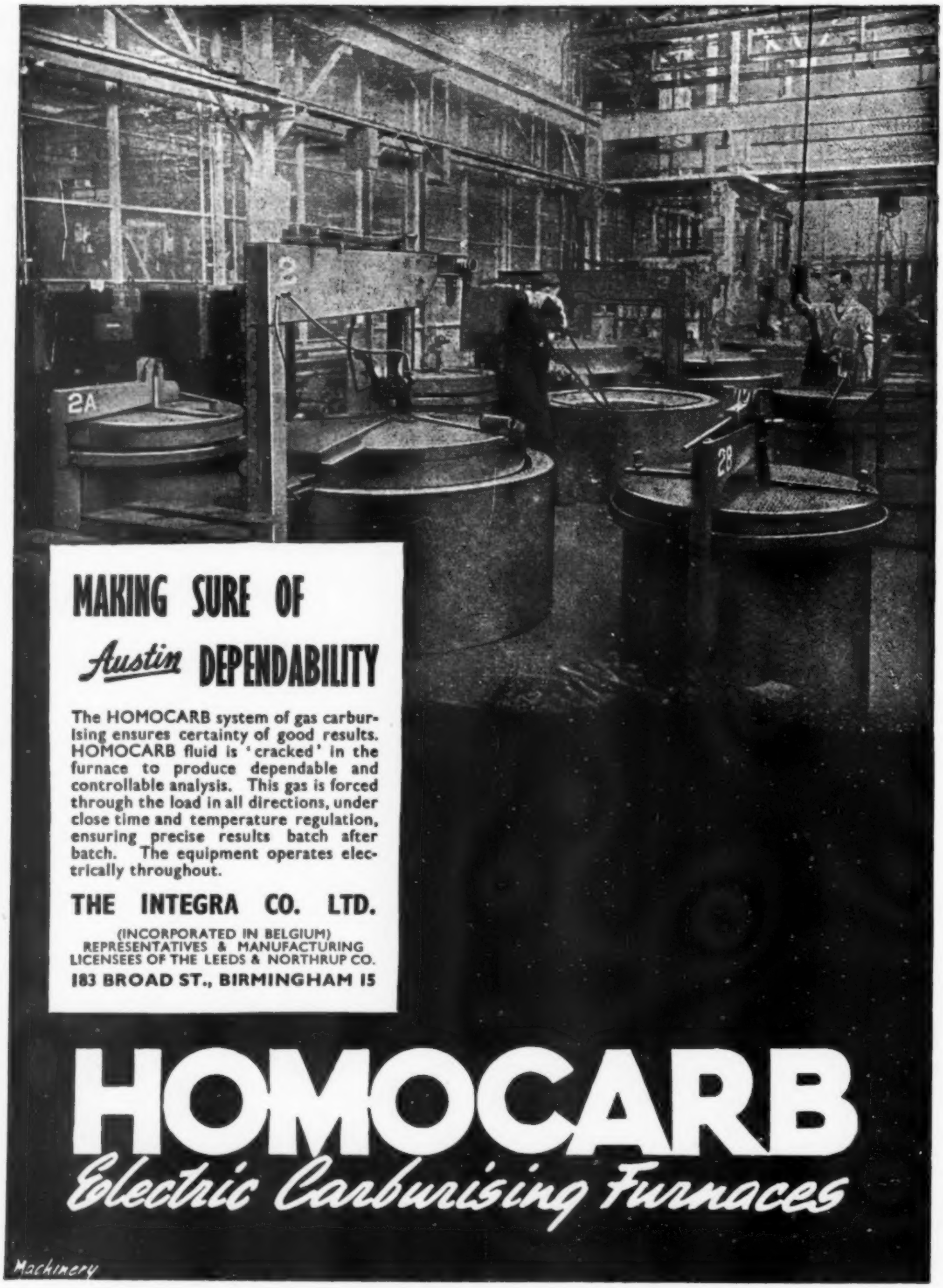

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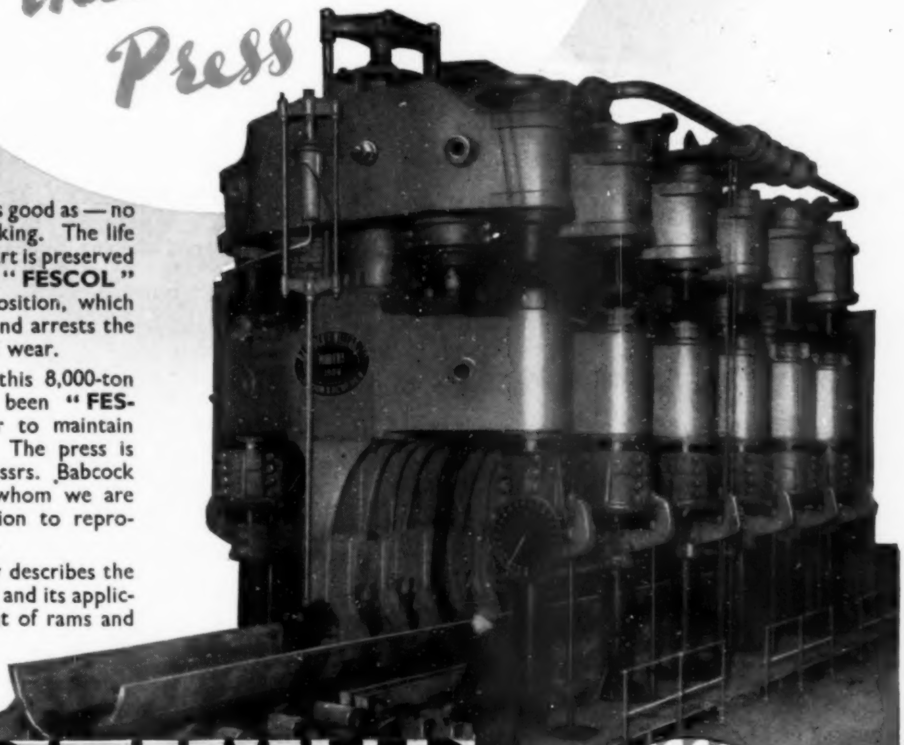

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to maintain efficiently this 8,000 ton Press

A hydraulic ram is as good as — no better than — its packing. The life of this vital working part is preserved and prolonged by the "**FESCOL**" process of metal deposition, which eliminates corrosion and arrests the progressive effects of wear.

Over 70 rams on this 8,000-ton Bending Press have been "**FESCOL**"-ised in order to maintain maximum efficiency. The press is the property of Messrs. Babcock & Wilcox, Ltd., to whom we are indebted for permission to reproduce the photograph.

List No. M.U.4 fully describes the "**FESCOL**" process and its application to the treatment of rams and many other parts.

FESCOL LIMITED

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LIGHTWEIGHT **LYRICS**

Number Twelve

ALFRED THE ALPINIST,
Climbing up the hills ;
Hanging on to tufts of grass
Brings him many thrills.

Asked why he's not become
" Alfred, the late ",
He puts his survival down
To being light in weight !

TJP aluminium alloys are always climbing in the esteem of their users. They are perfect examples of the survival, not merely of the lightest, but of the FITTEST in EVERY respect for the work they have to do. Of course all standard specifications are available. Then there are some particular pets of our own which a number of customers consider worthy of frequent repeat orders. But these are not all. Our research people delight in devising the new and novel, so if you want a special aluminium alloy for an unusual purpose let PRIESTMANS co-operate in its production. Remember, you can always rely on a TJP aluminium alloy being consistent to the original specification.

ALUMINIUM TPJ BRAND ALLOYS

T. J. **PRIESTMAN** LIMITED
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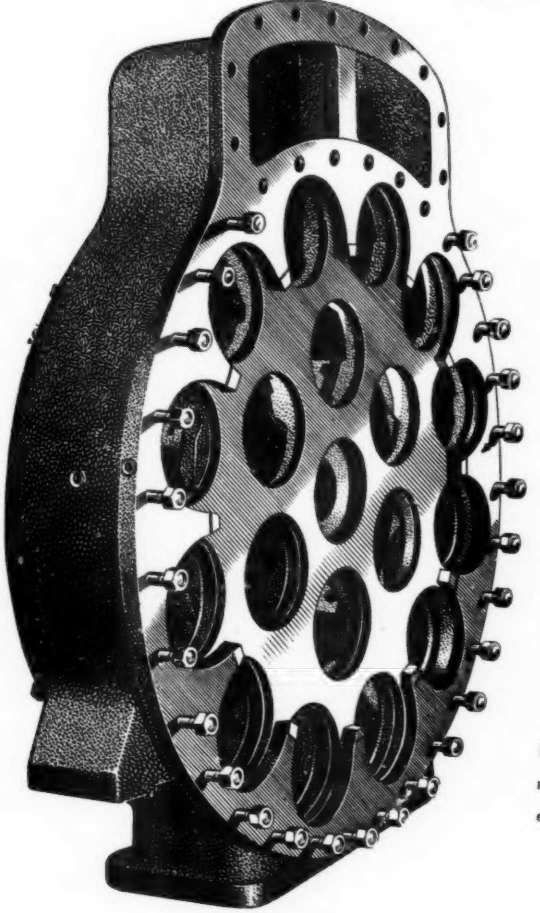
For better quality castings..



Treat the molten metal with Sodium Carbonate to:

- ★ reduce the sulphur content
- ★ eliminate sulphide segregation
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- ★ minimise porosity
- ★ remove non-metallic inclusions

Valve cover for a 10,000 cu. ft. air compressor. Perfectly clean, de-gassified metal with no trace of porosity was essential to produce successfully a casting of such intricate design and involving so much accurate machining.

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SODIUM CARBONATE

For details of the Sodium Carbonate process write to:

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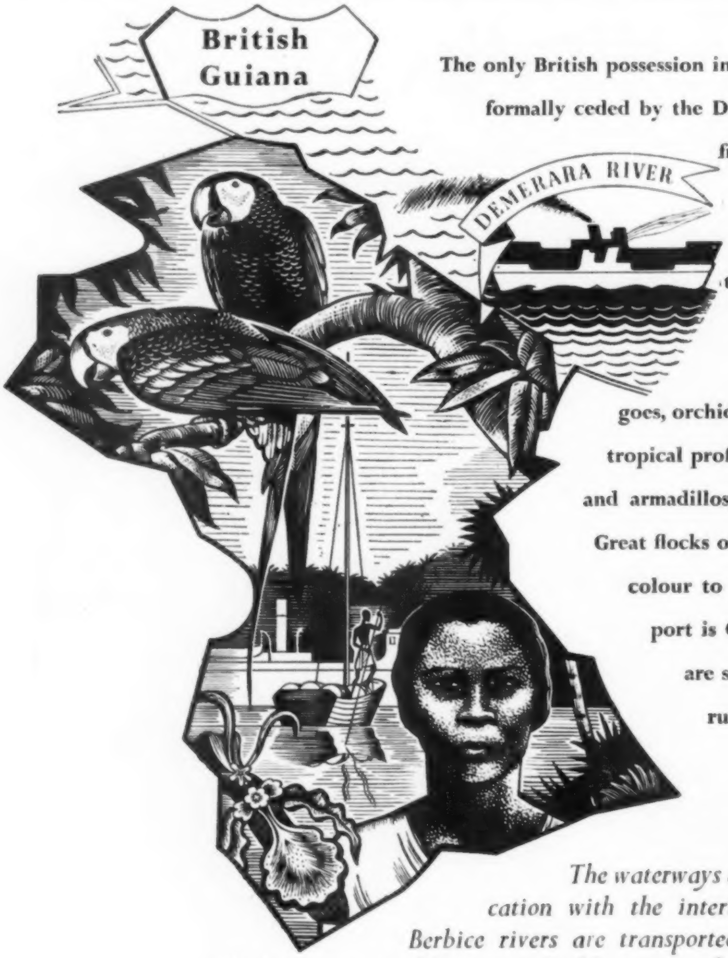
A Chapter in British Commonwealth Enterprise



The only British possession in South America, British Guiana was formally ceded by the Dutch in 1814-15. The country varies from the fertile coastal plain to high table-lands and mountain ranges. Dense forests supply valuable timbers—greenheart, wallaba, mora, purpleheart, crabwood and cedar. Plantains, palms and mangoes, orchids and other exotic flowers grow in tropical profusion. In the jungle there are tapir and armadillos, ocelot, labba, puma and jaguar. Great flocks of macaws and parrots give brilliant colour to the forests. The capital and chief port is Georgetown. The principal exports are sugar, bauxite (aluminium ore), rice, rum, diamonds, balata, timber, gold.

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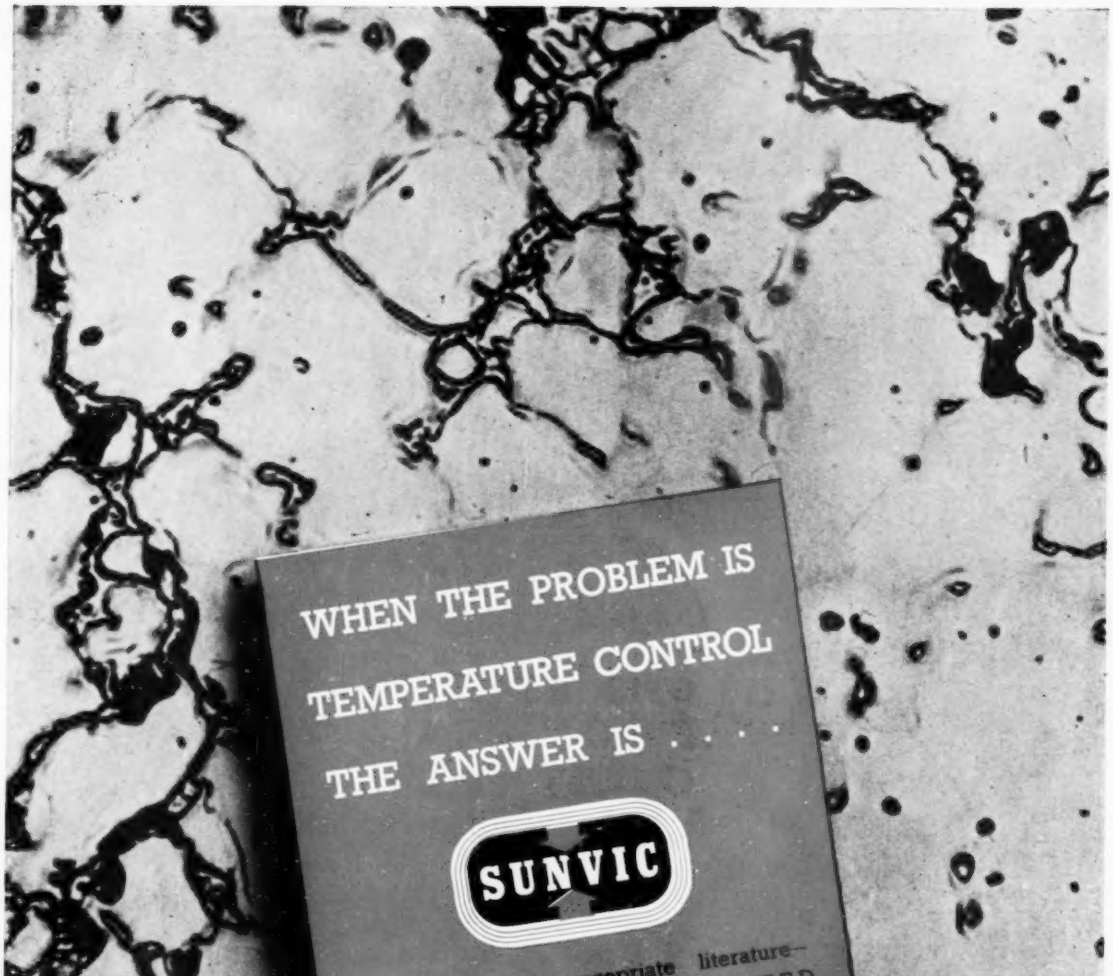

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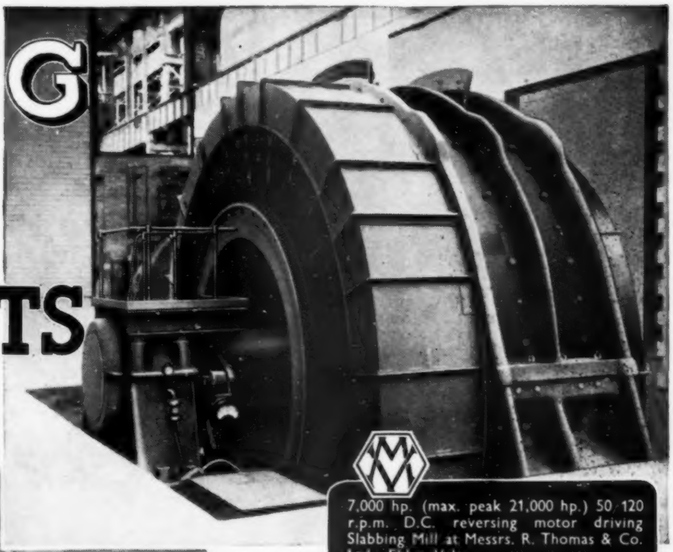
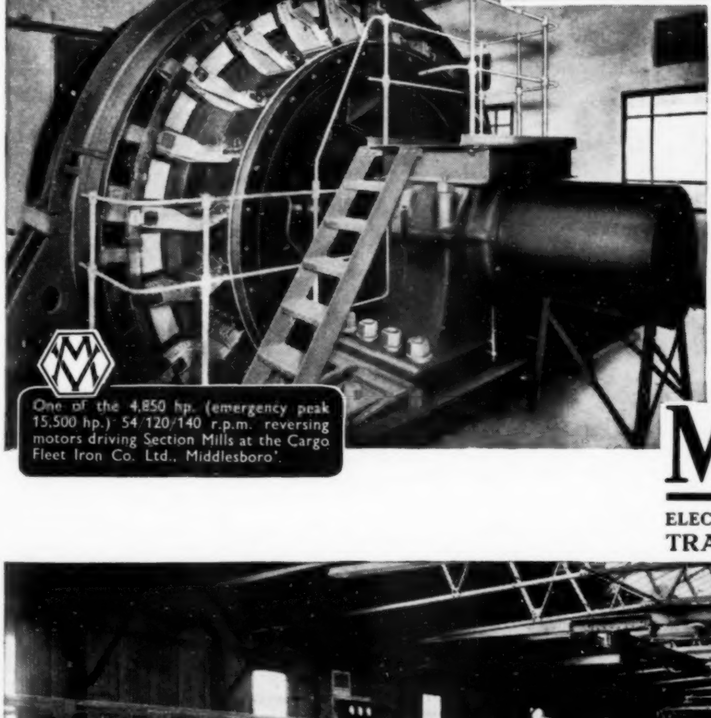


7,000 hp. (max. peak 21,000 hp.) 50/120 r.p.m. D.C. reversing motor driving Slabbing Mill at Messrs. R. Thomas & Co. Ltd., Ebbw Vale



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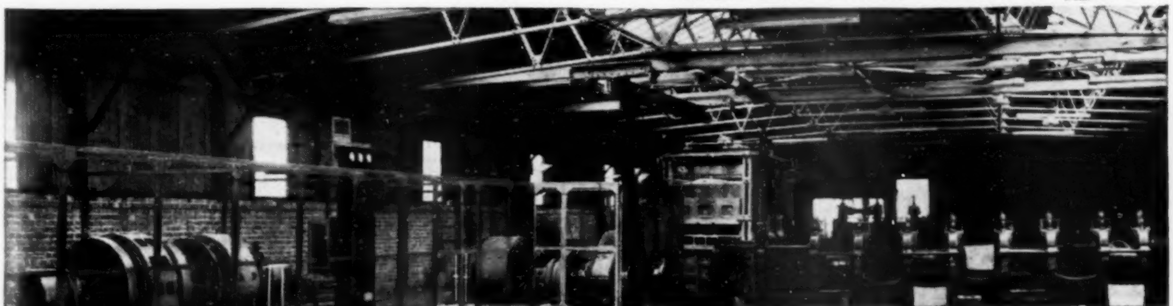
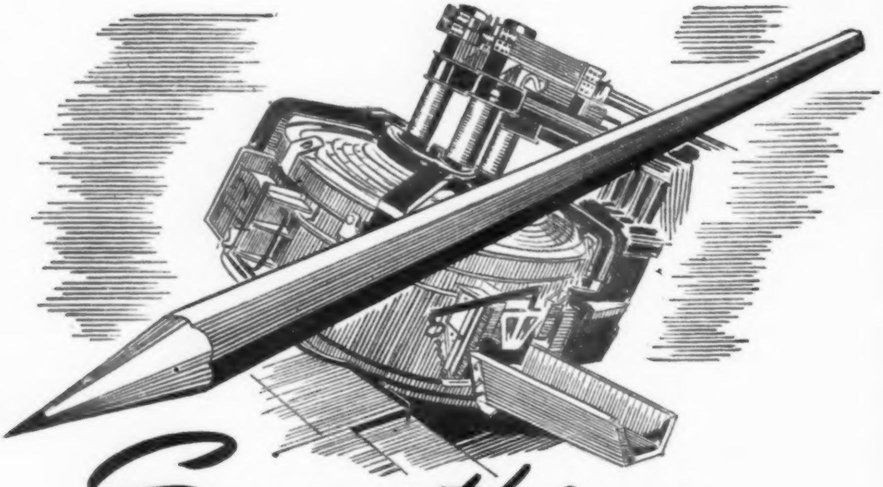


500 hp. 475/950 r.p.m. (max. peak 1,000 hp.) D.C. motor driving Rolling Mill at Messrs. British Driver-Harris Ltd., Cheadle Heath, with the m.g. set and D.C. panel on left.

C/S 801



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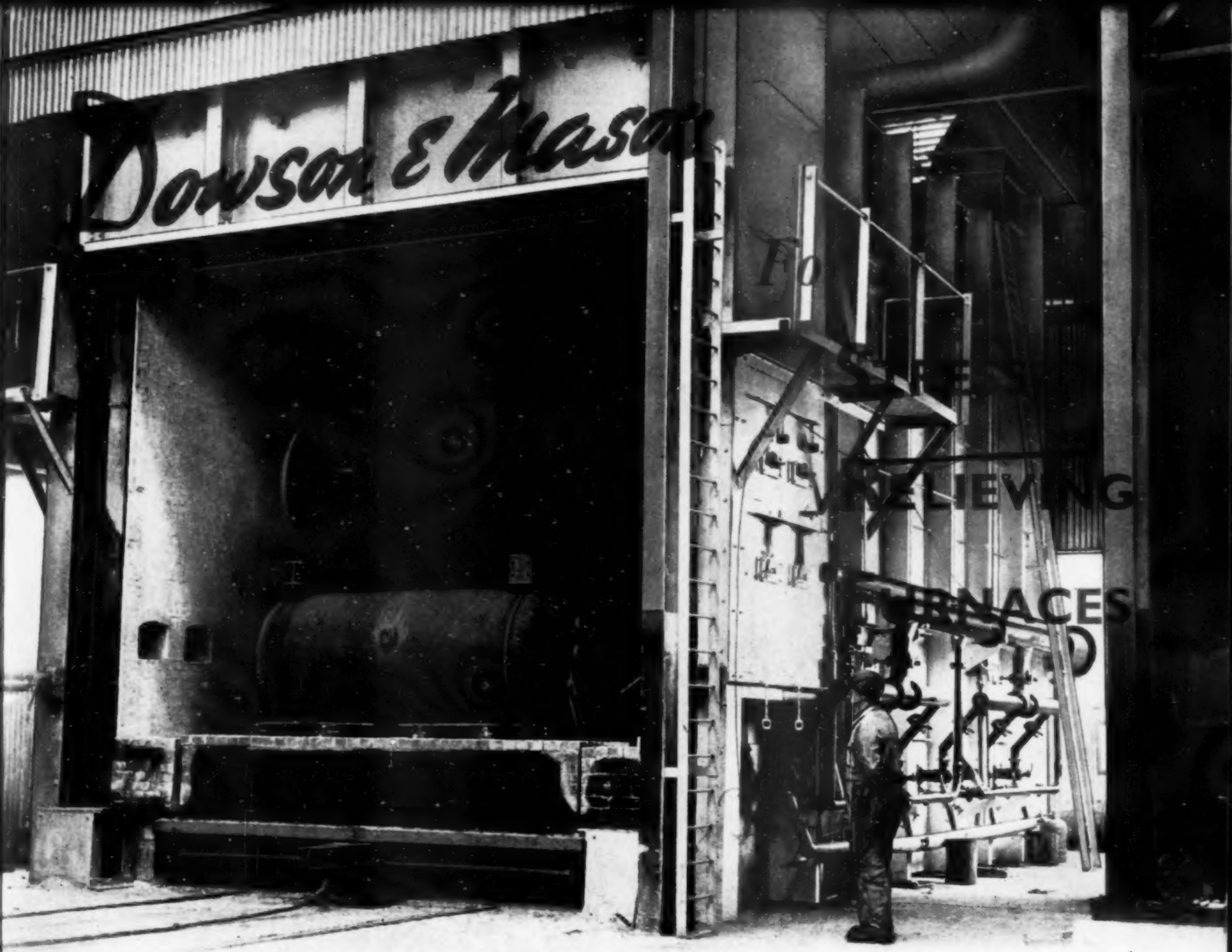

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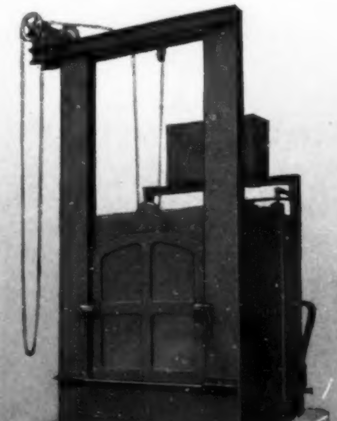

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JULY 1949 Vol. XL No. 237

Minerals and Civilisation

PRIMITIVE man had few utensils and no machines worth mentioning, but the things that made history, that helped him more in his struggle for existence and towards a more abundant life, were things of metal. To-day the material welfare of a nation can be measured by its consumption of minerals, the application of which indicate man's progress in physical comfort and well-being. Everyone knows that coal and iron are essential to our modern civilisation, not everyone, knows, however, the great importance of the rarer metals. Indeed the whole of our material civilisation depends on drawing on the capital resources of the earth. The importance of this is emphasised by the Fourth Empire Mining and Metallurgical Congress which commenced a very extensive programme of activities in London on July 9th and will continue at various centres until July 23rd. This Congress has brought together men of great knowledge and experience from many remote parts of the world to discuss progress in the discovery, mining and utilisation of the minerals of the Empire.

In our next issue we shall be giving special attention in our literary pages to exhibits at the Engineering and Marine Exhibition to be held at Olympia, London, from August 25th to September 10th, 1949.

The extent to which metals are now employed is indicated more clearly by making a broad comparison. For instance, the total consumption of metals and minerals during all the centuries before 1800 was quite insignificant compared with modern needs—probably less than it now is in a single year—and the total output of the world's mines, quarries and wells before 1900 is far behind that produced during the years of the present century. Until the revolutionary period, foods, fibres and wood were the chief materials of industry, and not more than half a dozen metals were employed to any appreciable extent. As recently as the beginning of the present century, the list of useful metals comprised iron, copper, lead and zinc, supplemented by very small quantities of tin, antimony, gold, silver, platinum and a few minor metals. Mercury and bismuth were used medicinally and to a meagre extent in the arts, but nickel and cobalt, in common with manganese and silicon, were employed very little outside the steel industry. The chemical industries and other large industrial consumers of mineral raw materials were in their infancy, and even architects and builders were satisfied with relatively few kinds of structural materials.

Since the beginning of the present century the number of metals in active use has more than doubled, and to-day research proceeds at a quicker pace to expand our knowledge, and, if possible, our utilisation of all the 92 elements that are recognised as comprising the essential materials. The three most abundant elements in the earth's crust that are stable, when isolated from their combinations, are aluminium, iron, and magnesium. The rapid growth in production of the light metals, aluminium and magnesium, confirms the prophecy that eventually they may rival iron in industrial utility. Silicon, calcium, sodium, and potassium are even more abundant than magnesium, and although none of them except sodium is used so extensively in the metallic state, their compounds have great industrial importance. Next to magnesium, titanium is the most abundant metal; it is half again as abundant as carbon. And the so-called rare metals are not rare at all. There is probably more cerium in the world than there is mercury or antimony, and the probable supply of the group as a whole is greater than that of zinc, lead, or several other common metals. Nevertheless, the uses of the rare-earth elements are very limited. Tellurium is available in much larger quantities than are needed at present. Gallium, germanium and indium are by-products of the zinc industry that could be recovered in larger quantities if they were wanted; but, as scientists become more expert in the rearrangement of atoms, a wider choice of raw materials will be available.

As pointed out by Sir Henry T. Tizard in his Presidential Address to the Congress, most minerals have been found accidentally and while such accidental discoveries are not at an end, they cannot be relied on for the future. Nor can reliance be placed entirely on the classical geologist, great though his help has been in the past. The mining geologist must now become more and more an applied physicist and apply all the techniques that physicists can apply. Such an applied science needs to be continuously developed on a firm foundation of fundamental knowledge. The last stage in providing metals for the ever more stringent requirements of engineers rests with metallurgists, and great strides have been made in recent years in the science of metallurgy. Many physicists are still absorbed in the problems of the atom and as a result of increased knowledge in this field clear scientific principles have been developed which can guide the practical metallurgist in his work. It is still true to say, that it is not possible to predict with any degree of certainty what combinations of metals are likely to be needed for certain purposes, but knowledge is ever increasing and making us more aware of that possibility.

Never before has man been so dependent on minerals, and never before were there so many opportunities to find new uses for them. It would be venturesome to predict which consuming industries afford the best opportunities, but it would seem that the minerals most likely to find new uses in the future, even more than in the recent past, will be those that are abundant in nature and can be produced at low cost.

Management in the Foundry Industry

At the second management conference held recently by the Council of Ironfounding Associations at Ashorne Hill, near Leamington, nearly a hundred managers and other executives were present. The new chairman of the Council, Mr. N. P. Newman, presided and the subjects discussed included productivity, human relations, amenities and marketing.

On the subject of productivity Mr. C. D. Hunter surveyed the principles involved and stressed the need for industrialists to adopt improved methods to achieve quality and increased production. Many leading firms, he said, had instituted a separate function in their organisations for this purpose and had reaped an adequate reward. Quality and increased production were complementary. This was especially true in the iron-founding industry, where the elimination of wasters contributed directly to increased production. Mr. Hunter dealt with the development of "work measurement," as a means of enabling production control to function effectively, as a basis for reliable costing, and as a method of providing an incentive to the workers. He emphasised the value of such incentive schemes in attaining satisfactory production and high worker morale, if there were honesty of purpose in respect of both workers and management, and all time studies were made available to the former, showing relaxation for fatigue, personal needs, etc. He also referred to the "preventive maintenance" which mechanisation called for, and on the subject of costing he spoke of the accurate control of expenditure through flexible budgets and the application of standard costs, indicating how reliable cost information can further the sales effort and provide the greatest profit.

Colonel W. A. Grierson, D.S.O. supporting the views of Mr. Hunter, explained in a graphic manner how the Lancashire cotton industry, benefiting from the experience with work measurement gained, between the wars, in certain European countries, is developing work measurement, standard costs, production planning, flexible budgets and cost control. He finished his survey by referring to the redeployment which was now being put into effect.

In his remarks at the opening of the Conference, the Chairman had stated that the greatest problem in industry to-day was the human problem, and the first speaker on human factors, Dr. C. B. Frisby, made the important point at the outset that "human relations" must be interpreted literally as relations between real people. Abstract concepts of management and personnel could cloud our thinking. Good relations had a positive character—absence of discord was not a sufficient criterion—evidenced by the will to co-operate. Human relations in industry depended on the attitudes of people to each other and to their work. Attitudes were affected not only by personal qualities but by history and tradition, social and economic factors, and physical and psychological aspects of the working environments. Dr. Frisby dealt in turn with all of these. He concluded by saying that managers must be ready to take the lead in developing better relations—their attitudes would largely determine the rate of progress.

Introducing the discussion on this subject of human factors, Mr. H. Weston Howard, C.B.E. gave an account of how joint consultation had been applied in his own company over the past 15 years. He made clear that any suspicion between workers and management could be banished by complete frankness. He corrected the mistaken idea that joint consultation required a management to give up its managerial prerogative. Committees were useful for advice and for policy making, but were not good for executive use. The two principles that Mr. Howard thought should be used in joint consultation were : (1) Management must always manage—it could not give up its responsibilities to the workers ; and (2) consultation should always take place between one rank and the next above it. He described the pyramid structure of the committees in his organisation, with the Joint Production Committee at the bottom level and the Policy Committee at the top of the pyramid. This Policy Committee would discuss everything—including profits. He concluded by affirming that to obtain the best human relations we must have some spiritual strength behind us.

The third session dealt with the installation and conduct of ablution centres ; reference is made elsewhere in this issue to the opening of a new centre. A round-table discussion under the chairmanship of Mr. J. W. Gardom took place between representatives of equipment manufacturers, ironfoundry owners and professional advisers. They were agreed that the siting of an ablution centre in a works was an important factor in determining the amount it was used, and that it should be between the foundry and the main works entrance, and for economy to be operated in conjunction with the canteen. Recommendations and individual preferences in connection with construction, lay-out, conduct and maintenance were expressed by the different speakers from their special viewpoints. Some guidance was also given as to the extent of use that the management might reasonably anticipate while a centre was still in the planning stage. Finally, the discussion group agreed that good ablution centres could attract labour into the industry and also help to put up the rate of production.

In the last session Mr. W. H. Harper directed particular attention to the selling methods applied in the industry. He referred particularly to press advertising and the sales representative. He examined various advertising techniques which had been successfully employed in the past and declared himself now in favour of the advertisement which confined itself to one idea or one product. Most convincing was the advertisement in which the ironfounder could link his own name with that of a satisfied customer whose trade-mark was well known. Mr. Harper's address was supplemented by a short paper from Mr. C. J. Lake, who emphasised that one thing consistently sold castings, and that was *good* castings. A sales organisation must have confidence in the product it had to sell. To increase the industry's overall sales of castings the general standard from *all* foundries must be improved. Where sales representatives were employed they should have a technical background and be thoroughly schooled in their company's production methods, and have a working knowledge of design problems. The representative should not be considered only as a salesman, he should follow the castings right through to final machining and report progress. Mr. Lake described the types of advertisement which he thought were successful, and others which were not, and in agreement with Mr. Harper he advised against trying to make a single advertisement cover too large a field.

The Creep of a Nominally Isotropic Aluminium Alloy Under Combined Stress Systems at Elevated Temperatures

By A. E. Johnson, M.Sc., M.Sc.Tech., A.M.I.Mech.E.

(Communication from the National Physical Laboratory)

The work described in this paper is part of a programme of creep, plastic strain and relaxation tests at high temperatures, and under general stress systems being carried out in the Engineering Division, National Physical Laboratory. The purpose of the present investigation was to examine the nature of the creep properties of an initially isotropic cast aluminium alloy (RR.59) at temperatures of 150° and 200° C., and under general stress systems. Some forty to fifty tests consisting of pure tensile, pure torsion, and complex stress creep tests (the latter under various combinations of simple tensile and torsion stresses) have been performed on the aluminium alloy at 150° and 200° C. The results of these tests have been analysed and equations for the stress-strain relations for the aluminium alloy over the temperature range concerned have been derived.

Introduction

SEVERAL experimental investigations of the behaviour of metals in creep under general stress systems have been made, and also a considerable amount of theoretical work has been done in attempts to establish the relations between the creep rates and the complex stress systems producing them.

A detailed consideration of the theoretical treatments suggested up to that time was given in the paper by H. J. Tapsell and the author,[2] and there is little need to repeat this in detail, but for the sake of completeness, a brief summary of the trend of these earlier theories will be given below, and additionally a more detailed consideration of the theory advanced by W. Prager[15] quite recently, which is of a considerably more general nature than any preceding theoretical work of which the author is aware.

The majority of the theories so far advanced are based on four assumptions which lead to a generally similar type of equations in all cases. These assumptions are as follows :—

1. The principal axis of stress and of strain are coincident, and remain so during plastic strain up to moderate amounts.
2. The volume of the material remains unchanged during plastic strain.
3. The three principal shear strains are proportional to the three principal shear stresses.
4. That plastic strain or yielding follows the criterion of shear strain energy, or octahedral shear stress.

For the assistance of readers familiar only with the metric system or preferring to use this system, the factors for converting British to metric units are given below :—

Length	.. ..	1 in. = 25·40 mm.
Stress	.. ..	1 t/in.^{2} = 157·43 Kg./cm.^{2}

If C_1, C_2 and C_3,* be the principal creep rates, and σ_1, σ_2, σ_3 the principal stresses, then the first three assumptions can be expressed by the equations :

$$C_1 + C_2 + C_3 = O$$

$$\frac{(C_1-C_2)}{(\sigma_1-\sigma_2)} = \frac{(C_2-C_3)}{(\sigma_2-\sigma_3)} = \frac{(C_3-C_1)}{(\sigma_3-\sigma_1)} = C$$

Nomenclature Used

The nomenclature employed is as follows:—

Applied tensile stress	t
Applied torsion stress	s
Major Principal Stress	σ_1
Minor Principal Stress	σ_2
Secondary Principal Stress	σ_3
Axial Creep Rate	C_a
Shear Creep Rate	C_c
Creep Rate in Direction of Major Principal Stress	C_1
Creep Rate in Direction of Minor Principal Stress	C_2
Creep Rate in Direction of Secondary Principal Stress	C_3
Angle Between Direction of Major Principal Stress and Axis of Specimen	ϕ
Ratio $^s/_t$	a
Quantity $1 + 4a^2$	b
Octahedral Shear Stress	σ_o
Octahedral Shear Creep Rate	C_o

Strain Tensor of Principal Strains E_1, E_2, E_3 denoted by E.

From these two equations creep strain-stress equations can be derived of the type :

$$C_1 = A\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

where A may be either a constant or an invariant of the stress system. It may be noted that the three assumptions upon which these equations are based were originally put forward as a basis for plastic theory by St. Venant[1] in 1870, and were based on experiments by Tresca. In the case where A is a constant the equations correspond directly to the original St. Venant theory. In the case where A is an invariant, several theorists have determined its nature by reference to the fourth assumption stated above, and in such cases A is a function of the shear strain energy. The equations are then said to correspond to modified St. Venant theory, or are described as St. Venant-Von Mises equations. In this latter case the equation is of the general form :

$$C_1 = F\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \quad \text{etc.} \quad .. \quad (a)$$

where F denotes a function.

In accordance with this form Odquvist has used the equations :

---

* See list of nomenclature used.

$$C_1 = A \left[\Sigma(\sigma_1-\sigma_2)^2\right]^m \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \quad \text{etc. (ref. 3)}$$

while Marin and Soderberg used the equations :

$$C_1 = \frac{A}{2^{\frac{(n+1)}{2}}} \left[\Sigma(\sigma_1-\sigma_2)^2\right]^{n-\frac{1}{2}} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc. (ref. 7 \& 6)}$$

Nadai has regarded A as effectively a variable viscosity function, dependent on the operative stress system, and expressed as :

$$C_1 = \left[\frac{(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)}{\phi}\right]$$

where ϕ is the inverse viscosity coefficient in question[8].

Two varieties of equation not in line with the above principles are those of Kanter and R. W. Bailey. Making use of an experimentally based equation for the case of tensile creep :

$$\phi C_1 = \sigma e^{K\sigma}$$

where C_1 is the creep rate, and ϕ a function of viscosity, Kanter suggested the equations :

$$\phi C_1 = \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] e^{K\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]} \text{ etc. (ref. 5)}$$

which do not of course correspond with the basic assumption (2). On this account these equations have not been considered in interpreting the results of this paper, since experimental work has shown that for deformations of the order considered in this paper assumption (2) is closely correct.

R. W. Bailey has used experimentally based equations of type :

$$C_1 = A\left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n\right] \quad \text{etc.} \quad \ldots \quad \ldots \quad \ldots \quad \ldots (b)$$

where A is a power function of shear strain energy[4].

These equations do not of course conform with the basic assumption (3), although the principal creep rates depend on the ratios of the three principal stresses, but Bailey showed considerable experimental evidence in their support.

It is to be noted that equations of type (*b*) may be generalised in the form :

$$C_1 = A_1\left[(\sigma_1-\sigma_2)^{n_1} - (\sigma_3-\sigma_1)^{n_1}\right] + A_2\left[(\sigma_1-\sigma_2)^{n_2} - (\sigma_3-\sigma_1)^{n_2}\right] + \ldots \text{etc.}$$

where A_1 and A_2 are of the same form as in the first equation, without losing conformity with such of the assumptions (1) to (4) as they fulfil in their simple state.

W. Prager[15] has recently treated the matter of stress-strain relations in a very general manner by expanding the strain in terms of the sum of power functions of the stress deviators :

$$S_1 = \left[\sigma_1 - {}^1/_3\, \Sigma\, \sigma_1\right]$$

or in terms of the nomenclature used above :

$$S_1 = {}^1/_3\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

(A similar approach to this matter has been made in several recent papers by M. Reiner).

For example in the case of pure tension :

$$\epsilon_1 = C_1 S_1 + C_3 S_1^3 + C_5 S_1^5 + \ldots\ldots\ldots$$

odd powers of S_1 being used, because reversal of the sign of S_1 is assumed to lead to mere reversal of the sign of ϵ_1.

When equations of this nature are applied to the case of complex stress, any power of S_1, say S_1^5 must be replaced not by the corresponding power of the stress deviators, but by an expression which is homogeneous in the fifth order in stress components—e.g. :

$$aJ_2^2S + bJ_2S^3 + cS^5 + dJ_2J_3I$$

where a, b, c, d, are constants. J_2 and J_3 are invariants :

$$J_2 = \tfrac{1}{2}(\Sigma S_1^2),\ J_3 = {}^1/_3(\Sigma S_1^3),$$

and I is the unit tensor of principal values unity.

The constants a, b, c, d, are determined so that the sum of the principal values vanishes identically, and its first principal value reduces to S_1^5 in the case of simple tension and compression.

The Hamilton-Cayley* equation for stress deviators states that :

$$S^3 = J_2S + J_3I,$$

and by use of this relation, and conformity with the conditions just mentioned, it can be shown that the strain tensor E can be expressed in terms of expressions of either the first or second powers in S for complex stress systems, and can finally be written :

$$E = f(J_2, J_3^2)\left\{p(J_2, J_3^2)\, J_3T + q(J_2, J_3^2)\, S\right\}$$

where p and q are polynomials in J_2 and J_3^2, f a function of J_2 and J_3, and $T = S^2 - {}^2/_3\, J_2I$.

The values of the function in brackets in this equation are always homogeneous forms of the stress components, the degree of p being lower by 4 than that of q.

The principal values of E are :

$$E_1 = f(J_2, J_3^2)\left\{p(J_2, J_3^2)\, J_3(S_1^2 - {}^2/_3J_2) + q(J_2, J_3^2)\, S_1\right\} \text{ etc.}$$

which obviously fulfills assumption (2) in a very general manner.

As in the case of the Bailey equations assumption (3) is not in general fulfilled, but the ratios of principal strains are dependent only on the ratios of the three principal stresses.

The generality of this equation of Prager's is very great, and it can be used to represent a wide variety of stress-strain relations (Prager has shown for instance that Bailey's equations are a particular case of the above general form.) By transposition of the time dependent functions C_1, C_2, C_3, for the strains E_1, E_2, E_3, the above equation represents the case of creep.

Previous Experimental Work

The general problem of creep under complex stress systems is most simply studied under systems consisting either of simple tension combined with simple torsion stresses, or alternatively internal pressure with or without axial stress, and such systems appear to have been the subject of all investigations so far.

The work of R. W. Bailey[4] on a 0·115% C steel, and on a 0·45% C steel at 480° C. under combinations of tension and torsion, and on lead tubes at room temperature, under internal pressure and axial load, led him to the conclusion that in general a relatively complex relation existed between creep stress and strain, in which the creep rates were dependent on power functions of both the shear strain energy, and the maximum shear stresses of the complex stress system.

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* See Bôcher, M., Introduction to Higher Algebra. Macmillan Co., New York, 1907, p. 26.

Jamieson[16] made torsion and tension creep tests on lead tubes at 25° C., and comparing the tensile and torsion relations with those computed on the basis of an assumption of modified St. Venant theory found some measure of agreement.

Everett and Clark[10] carried out tests in tension and torsion of 0·5% molybdenum steel at temperatures of 427° and 538° C. for periods varying between 1,000 and 1,500 hours, comparing values of the characteristic exponents of the material measured in tension with those computed from the torsion tests on the basis of an assumption of the modified St. Venant theory. Agreement appears to have been good.

F. H. Norton[11] made experiments on the creep of tubular specimens closed at the ends, and subject to internal pressure, and in addition pure tension tests, on what were nominally the same steels as were used by Everett and Clark at 482° and 566° C. The periods of test varied from about 2,600–6,400 hours. Some agreement with modified St. Venant theory was obtained. Analysis of the results of Everett and Clark, and of Norton, by E. A. Davies[12] on the basis of the octahedral plane sections indicated considerable difference between materials used, possibly due to a condition of anisotropy.

Finally, work has lately been completed at the National Physical Laboratory on behalf of B.E.A.I.R.A. J/E Committee, in which some eighty creep tests under pure tension, pure torsion, and various combinations of simple tensile and torsion stresses, have been performed on a 0·17% C steel at 350°, 450° and 550° C.[14] The results of these tests at 350° C. indicated that at this temperature the material was essentially isotropic except at the highest stresses, and here it seemed probable that the anisotropy may have arisen as a result of directional properties acquired under considerable plastic strain on loading. The octahedral shear strain appeared for all stress systems to be closely a function of the octahedral shear stress, i.e.—the Hencky criterion of plastic flow appeared to be fulfilled approximately for the material.

Principal Creep Rate-Stress Relations

The principal creep rate-stress relations at a specific period over the whole range of stress and time investigated could reasonably be represented by equations of the form :

$$C_1 = \left\{ A \left[\Sigma(\sigma_1-\sigma_2)^2 \right] + A^1 \left[\Sigma(\sigma_1-\sigma_2)^2 \right]^m \right\} \left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

where A, A^1, are constants and m = 2·5. The effect of the anisotropy present at the highest stresses appeared to be merely to redistribute the creep between secondary and minor principal stress directions, leaving the major principal stress as it would have been for complete isotropy.

For the moderate and lower ranges of stresses the relation becomes :

$$C_1 = A \left\{ \Sigma(\sigma_1-\sigma_2)^2 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

These equations conform with the St. Venant-Von Mises general type, and also since :

$$\left\{ \Sigma(\sigma_1-\sigma_2)^2 \right\} \left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1) \right] \equiv \left[(\sigma_1-\sigma_2)^3 - (\sigma_3-\sigma_1)^3 \right]$$

they conform with the Bailey type of equation for n = 3.

At 450° C. slight anisotropy was shown at moderate and low stresses, although the further effect noted at 350° C. again occurred at the highest stresses with probably the same origin. At 550° C., however, a very complex condition of anisotropy occurred. It appeared possible that the anisotropy exhibited at 450° and 550° C. was associated with metallurgical changes occurring in the structure of the material at these temperatures, possibly resulting in the conferment of directional creep properties. However, at 450° and 550° C. despite the anisotropy present, it appeared probable that the Hencky theory was still the basis of the behaviour of the material.

At 450° C. equations of the form :

$$C_1 = \left\{ A \left[\Sigma(\sigma_1-\sigma_2)^2 \right]^{m_1} + A^1 \left[\Sigma(\sigma_1-\sigma_2)^2 \right]^{m_2} \right\} \left[(\sigma_1-\sigma_2) - C(\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

where A, A^1, C, m_1 and m_2, are constants, C referring to the anisotropy present, and $m_1 = 0.45$, $m_2 = 2{\cdot}45$ or alternatively :

$$C_1 = \left\{ A + A^1 \left[\Sigma(\sigma_1-\sigma_2)^2 \right]^m \right\} \left[(\sigma_1-\sigma_2)^n - D(\sigma_2-\sigma_3)^n \right] \text{etc.}$$

where m = 2, n = 1·9 and D is constant, referring to the anisotropy present, will represent the experimental results.

At moderate and lower ranges of stress the above equations become :

$$C_1 = \left\{ A \left[\Sigma(\sigma_1-\sigma_2)^2 \right]^{m_1} \right\} \left[(\sigma_1-\sigma_2) - C(\sigma_3-\sigma_1) \right] \quad \text{etc.}$$

$$\text{or} \quad C_1 = A \left[(\sigma_1-\sigma_2)^n - D(\sigma_2-\sigma_3)^n \right] \quad \text{etc.}$$

At 550° C. it was not possible to formulate general equations representing the stress creep rate relations. There was some evidence, however, that the bases of such equations would be similar to the general form given above for 350° and 450° C.

Particulars of Aluminium Alloys Tested

The material, Hiduminium RR.59 alloy was supplied by High Duty Alloys, Ltd., Slough, Bucks., in the form of a continuous cast billet 12 in. dia. and 18 in. long. Microscopic examination of the material indicated a satisfactorily small grain size after heat treatment at 525° C. ± 5° C. for 8 hours, and quenching in boiling water, followed by 24 hours at room temperature, and heating at 250° C. ± 3% for 16 hours with air cooling. A photomicrograph is shown in Fig. 1. Creep tests at 7 t/in.² and 200° C. on material cut longitudinally, circumferentially and radially from the billet gave closely similar results, and the creep properties were independent of the position of the specimen in the block. The indication was that the block was in a satisfactory condition of isotropy from the point of view of the creep tests to be carried out.

All test pieces used in the tests to be described were cut longitudinally from the block.

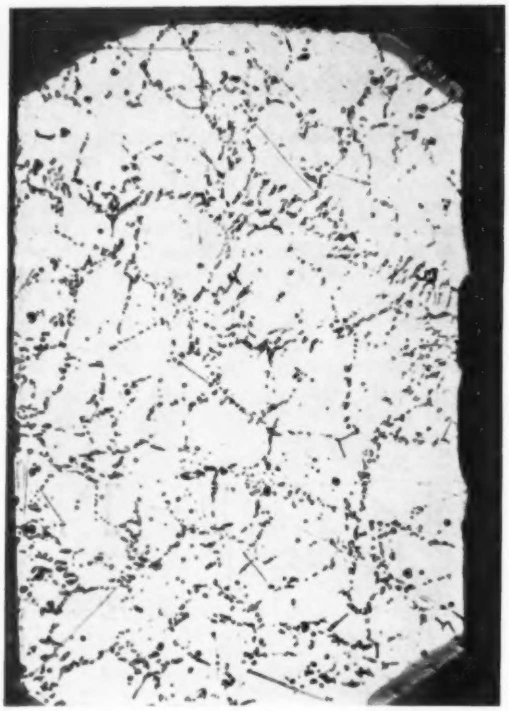

Fig. 1.—Photomicrograph of section of wall thickness of a tubular creep specimen. × **90**

Reduced to $\frac{2}{3}$ linear in reproduction

Form of Specimen Used

The tubular test piece used was of the form shown in Fig. 2. It was 0·5 in. external dia., and had a nominal wall thickness of 0·020 or 0·015 ± 0·0005 in. over a 2 in. parallel portion. In making a specimen a blank was first machined down to within $\frac{1}{32}$ in. of the largest diameter, after which the specimen was drilled through. The ends of the specimen were then turned down to size, and the centre portion reduced by light cuts to $\frac{11}{16}$ in. dia. The specimen was bored to within 0·0005 in. of finished size, and one end was internally screwed. Final machining and polishing of the central portion was carried out with the specimen on a mandrel, and keyways were cut in the ends. The specimen was finished by lapping the hole to correct size. Measurement of the external diameter, and of the wall thickness of each specimen was made at numerous positions along the parallel portion.

A measure of the degree of oxidation to be expected was obtained by suspending pieces of the aluminium alloy in furnaces maintained at the temperature of 200° C. for 200 hours. It was found that the oxidation was negligible. The stresses in the tests, therefore, remained equal to their initial value throughout the test period. (The order of the strains in the present tests was too small to give rise to appreciable changes of volume or cross-section).

Description of Test Apparatus

The main features of the testing machine, and strain measuring device used in the tests have been described in a previous paper.[2] The machine has since been modified in detail, the main change being that a furnace split horizontally at its middle section is now used, and controlled by an individual thermostat. By this means the gradient on the specimen is reduced to less than 2° C. at all temperatures while the temperature is controlled within $\pm\frac{1}{4}$° C.

Experimental Work

Only one creep test was carried out on each specimen The tests lasted about 150 hours, readings of creep strain being made at frequent intervals during the first day, and thereafter at intervals of a day. For the majority of tests the stresses were chosen to give a range of creep rates in the direction of maximum principal stress varying between 10^{-5} and 10^{-7} per hour, but one or two tests made to determine the trend of the characteristic creep rate-stress curves at high stresses gave rates exceeding the upper value.

The creep rates in the three directions of principal stress were computed from the measured axial and shear creep rates by means of the formulae :

$$C_1 = C_a + \frac{C_c}{2}\left[\sqrt{(t/2s)^2+1} - t/2s\right]$$

$$C_2 = C_a - \frac{C_c}{2}\left[t/2s + \sqrt{(t/2s)^2+1}\right]$$

$$C_3 = C_c\, t/2s - 2C_a$$

The derivation of these formulae is given in the Appendix of ref. 2 of the Bibliography. The octahedral shear creep rate was computed from the formula :

$$C_o = {}^2/_3\left[\Sigma\,(C_1 - C_2)^2\right]^{\frac{1}{2}}$$

This corresponds to the octahedral shear stress :

$$\sigma_o = {}^1/{}^3\left[\Sigma\ (\sigma_1 - \sigma_2)^2\right]^{\frac{1}{2}}$$

On account of the rather higher accuracy to be obtained in the pure torsion tests, enough of these tests were performed to enable the main features of the creep rate-stress characteristic curve under pure torsion to be well mapped out, thus forming a guide to the likely form of similar relations for other stress systems under which fewer tests were made.

At 150° C. seven pure torsion tests, two pure tension, and one or two tests in each of the stress systems ${}^t/_s$ = 0·4, 0·8, 1·5 and 3·0, were made ; while at 200° C., five pure torsion, six pure tension, three in each of the stress systems ${}^t/_s$ = 0·4, 0·8 and two tests in the stress systems ${}^t/_s$ = 1·5 and 3·0, were performed.

Results of Experimental Work

Curves of the axial and shear creep strains, plotted* against time over a testing period of 150 hours for each test were found in all cases to have the same geometrical form for each individual temperature. To determine the common form as precisely as possible, a comparison of the curves was made by plotting all the results in one diagram as in Figs. 3 and 4, which show the composite curves for all strain-time curves at 150° and 200° C.

Since the creep readings in the torsion tests were less affected by temperature variations than those in other

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* The creep strain shown is exclusive of the initial plastic strain in all cases. In the cases of one or two of the tests at high stresses the initial plastic strain was not accurately determined, and it was accordingly decided to omit this strain in all cases. Previous work has shown, however, that the characteristics of this portion of the strain though differing in kind from the subsequent creep strain nevertheless exhibit geometrical similarity among individual curves of various stress systems. The characteristics of this initial plastic strain are to be dealt with in detail in a subsequent paper.

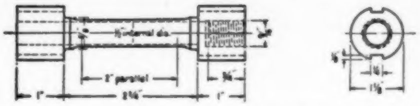

Fig. 2.—Form of test piece used in all tests.

tests, the mean form of the curves for the pure torsion tests was first ascertained, and plotted to a scale equivalent to that of a test at one of the highest torsion stresses. The creep reading for each of the other tests were plotted to modified scales of suitable magnitude to make the enhanced readings of each individual test fit the mean curve as closely as possible. The mean curve form for all the tests was then drawn through the points as shown in Figs. 3 and 4.

All the curves for the individual tests were drawn by appropriate reduction of scale, and were, therefore, geometrically similar. Errors in tests giving smaller strains are considerably magnified in Figs. 3 and 4. The curves for individual tests are shown in Figs. 5–10 for the two temperatures concerned.

The composite curve form is such that the creep rate varies with time as follows :

		Period of Test Hours					
Temperature °C. of Test		150	100	50	20	10	5
150	Ratio of Creep Rate to that at 150 hours	1	$1\cdot02_5$	$1\cdot17_5$	1·44	1·97	2·82
200	Ditto	1	1·41	2·33	3·5	5·4	8·33

Tables I and II, respectively, give the experimental values for the axial and shear creep rates in the various tests at 150 hours for the two temperatures 150° and 200° C. The values of the principal and octahedral creep rates given in Tables I and II have been computed for test periods of 150 hours at 150° and 200° C. making use of the equations given above, in the section on experimental work. The principal creep rates, and octahedral plane creep rates at other periods may be computed from the ratios given above.

It will be observed that at 150° C. the whole of the tests at the highest stresses are pure torsion. The reason for this is that two of the early tests in this region indicated that the creep rates increased very rapidly with increments of stress, so that this region was not of great practical interest. Accordingly since the supply of material for test pieces was somewhat restricted it was decided to map out this region with three or four tests only in pure torsion, this variety of test giving the highest accuracy of strain reading.

Two points are to be noted in connection with the results in Table I and II. It will be seen that at neither temperature is any axial creep shown in the pure torsion tests.* Secondly, except in one or two cases at 200° C., the creep in the direction of wall thickness is negative. The nature of the wall thickness creep in the one or two exceptional cases is bound up with anisotropy probably arising from the plastic strain occurring upon loading. This point is enlarged upon later in the paper.

Consideration of the Degree of Isotropy of the Material at 150° and 200° C

As previously indicated, creep tests at 200° C., and 8 t/in.^{2} on solid specimens, taken in three rectangular directions from the original billet, indicated that the creep characteristics of the material were closely similar in the three directions, and reasonably isotropic behaviour in subsequent tests on tubular specimens was therefore to be expected.

However, before performing the main body of the tests, a further test was made in tension on a tubular specimen at 8 t/in.^{2} and 200° C. The change in diameter and wall thickness of the specimen during the test period were measured and compared with the axial strain. The diametral strain was 0·10%, the wall thickness strain was of the same order, and the axial strain was 0·20%. Evidently, the secondary strains were roughly half the longitudinal strain, and the material is thus indicated to be isotropic. However, it should be noted that this test of isotropy is not the final word upon the matter, as a certain type of anisotropy can give the same distribution of creep rates between the three principal directions in pure tension as a state of isotropy. The chances that the material is isotropic are nevertheless considerably raised if this test is fulfilled.

A further test of isotropy is afforded by the plot of the experimental ratios $\frac{-\sigma_2}{(\sigma_1-\sigma_2)}$ against $\frac{-C_2}{C_1}$. This plot should tend towards the value $-C_2=0\cdot5$ for $\frac{-\sigma_2}{(\sigma_1-\sigma_2)}=0$, i.e., for pure tension, if the value is isotropic.

In Fig. 11 the plot is made for 150° C. for all combined stress tests undertaken, and it is evident that the

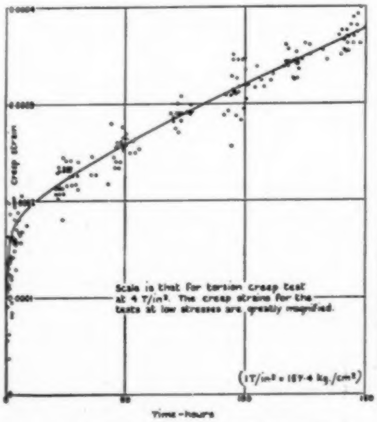

Fig. 3.—Composite creep strain-time curve for all tests at 150° C.

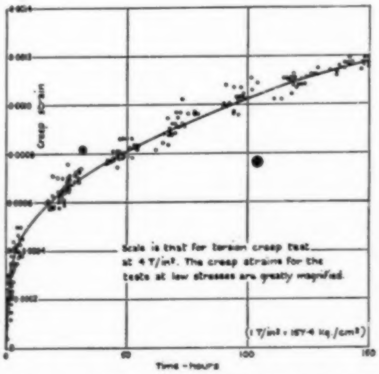

Fig. 4.—Composite curve for all tests at 200° C.

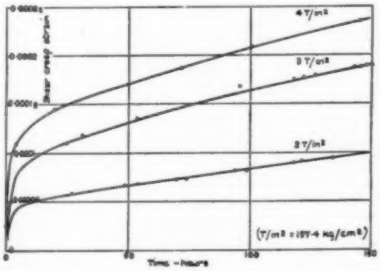

Fig. 5.—Creep strain-time curves under pure torsion stresses at 150° C.

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* Compare ref. (2), p. 3 and ref. (4), pp. 159 and 160.

TABLE I—RESULTS OF COMBINED STRESS CREEP TESTS ON RR.59 ALLOY AT 150° C. COMPARED WITH VALUES BASED

Tensile Stress t T/in.^{2}	Torsion Stress s T/in.^{2}	Principal Stresses T/in.^{2}		Octa-hedral Stress T/in.^{2}	Measured Axial Creep Rate C_a ×10^{-6}/hr.	Measured Shear Creep Rate C_e ×10^{-6}/hr.	Experimental Values				Ratio C_a/C_e	Ratio t/3s	Principal Creep Rates based on equations $C_1 = A[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)]$ where $A = 2\cdot55\times10^{-8}$, etc.		
		σ_1	σ_2				Principal Creep Rates × 10^{-6}/hr.			Octa-hedral Creep Rate ×10^{-6}/hr.			C_1	C_2	C_3
							C_1	C_2	C_3				× 10^{-6} hrs.		
8	—	8	—	3·77	0·40	—	0·40	−0·20	−0·20	0·57	—	—	0·41	−0·20$_5$	−0·20$_5$
3	—	3	—	1·41	0·14	—	0·14	−0·07	−0·07	0·20	—	—	−0·15$_5$	0·077	−0·077
—	9	9	−9	7·36	—	10^2–10^3	10^2–10^3	−10^2–10^3	0	10^2–10^3	—	—	—	—	—
—	8·5	8·5	−8·5	6·95	—	14	7	−7	0	11·5	—	—	—	—	—
—	8	8	−8	6·54	—	3·1	1·5$_5$	−1·5$_5$	0	2·5$_5$	—	—	—	—	—
—	7	7	−7	5·72	—	1·6	0·8	−0·8	0	1·32	—	—	—	—	—
—	4	4	−4	3·27	—	0·6	0·3	−0·3	0	0·49	—	—	0·31	−0·31	0
—	3	3	−3	2·45	—	0·49	0·24$_5$	−0·24$_5$	0	0·40	—	—	0·23	−0·23	0
—	2	2	−2	1·64	—	0·31	0·15$_5$	−0·15$_5$	0	0·25	—	—	0·15$_5$	−0·15$_5$	0
1·2	3	3·66	−2·46	2·51	0·061	0·37	0·21$_5$	−0·16$_5$	−0·05	0·32	0·16$_5$	0·133	0·25	−0·22	−0·03
3·2	4	5·9	−2·7	3·59	0·14	0·53	0·32	−0·25	−0·07	0·48	0·26$_5$	0·267	0·37	−0·29	−0·08
1·6	2	2·95	−1·35	1·8	0·10	0·36$_5$	0·22	−0·16$_5$	−0·057	0·31$_5$	0·28	0·267	0·18$_5$	−0·14$_5$	−0·04
6·7$_5$	4·5	9	−2·26	5·1	0·45	0·87	0·67	−0·42	−0·25	0·96	0·52	0·5	0·52	−0·34$_5$	−0·17$_5$
4	2·67	5·33	−1·34	2·88	0·21	0·42	0·31$_5$	−0·21	−0·10$_5$	0·45	0·5	0·5	0·31	−0·20$_5$	−0·10$_5$
8	2·66	8·8	−0·8	4·3$_5$	0·32	0·33	0·37	−0·22$_5$	−0·14$_5$	0·52$_5$	0·99	1·0	0·47	−0·26$_5$	−0·20$_5$
4	1·33	4·4	−0·4	2·17	0·21$_5$	0·21$_5$	0·25	−0·14	−0·11	0·35	1·0	1·0	0·23$_5$	−0·13	−0·10$_5$

general trend is towards the value 0·5, and the indication of the tests made at this temperature is that the material is behaving isotropically.

It must be noted, however, that complex stress tests at higher stresses than those actually made, might have shown the same type of anisotropy as is subsequently commented upon for some tests at 200° C., and for the same suggested reason.

Again also in Fig. 11 a plot is made for the temperature 200° C. for all except two high combined stress tests in which the wall thickness creep C_3 was positive indicating anisotropy. The trend of the curve in Fig. 11 is towards $0\cdot5$ for $\frac{-\sigma_2}{(\sigma_1-\sigma_2)} = 0$ indicating that isotropy is conserved at all except the highest stresses.

Some suggestions regarding the nature of the anisotropy occurring at higher stresses are put forward later in the paper.

Consideration of the Behaviour of the RR.59 Alloy at 150° C.

(a) Experimental creep rate—stress relations considered in relation to various theories at 150° C.

In a previous paragraph consideration has been given to the forms of stress-strain relations suggested by various theoretical treatments which have been put forward. It was shown that such experimental work as had been performed suggested that either equations of the form :

$$C_1 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

as suggested by Odquvist, Marin and Soderberg, and in a modified manner by Nadai, equations of the form :

$$C_1 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2)^n-(\sigma_3-\sigma_1)^n\right] \quad \text{etc.}$$

TABLE II.—RESULTS OF COMBINED STRESS CREEP TESTS ON RR.59 ALLOY AT 200° C. COMPARED WITH VALUES BASE

Tensile Stress t T/in.^{2}	Torsion Stress s T/in.^{2}	Principal Stresses T/in.^{2}		Octa-hedral Stress T/in.^{2}	Measured Axial Creep Rate C_a ×10^{-6}/hr.	Measured Shear Creep Rate C_e ×10^{-6}/hr.	Experimental Values Principal Creep Rates × 10^{-6}/hr.			Octa-hedral Creep Rate ×10^{-6}/hr.	Ratio C_a/C_e	Ratio t/3s	All Creep Rates Measured at 150 hours		
													Principal Creep Rates based on equations $C_1=A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0\cdot5}\left[2\sigma_1-\sigma_2\right]$ etc. where $A = 0\cdot74_5\times10^{-8}$		
		σ_1	σ_2				C_1	C_2	C_3				C_1	C_2	C_3
													× 10^{-6}/hr.		
8	0	8	0	3·77	5·3	—	5·3	−2·6$_5$	−2·6$_5$	7·5	—	—	—	—	—
7	0	7	0	3·3	1·53	—	1·53	−0·77	−0·77	2·16	—	—	—	—	—
6	0	6	0	2·83	0·64	—	0·64	−0·32	−0·32	0·90$_5$	—	—	0·75	−0·37$_5$	−0·37$_5$
5	0	5	0	2·36	0·42$_5$	—	0·42$_5$	−0·21$_5$	−0·21$_5$	0·6	—	—	0·52	−0·26	−0·26
4	0	4	0	1·89	0·32$_5$	—	0·32$_5$	−0·16	−0·16	0·46	—	—	0·34	−0·17	−0·17
3	0	3	0	1·41	0·18	—	0·18	−0·09	−0·09	0·26	—	—	0·19	−0·09$_5$	−0·09$_5$
0	4·75	4·75	−4·75	3·88	—	56	2·8	−28	0	46	—	—	—	—	—
0	4	4	−4	3·27	—	3	1·5	−1·5	0	2·4$_5$	—	—	—	—	—
0	3	3	−3	2·45	—	0·84	0·42	−0·42	0	0·69	—	—	0·50	−0·50	0
0	2·5	2·5	−2·5	2·04	—	0·72	0·36	−0·36	0	0·59	—	—	0·34	−0·34	0
0	2	2	−2	1·63	—	0·47	0·23$_5$	−0·23$_5$	0	0·38$_5$	—	—	0·22	−0·22	0
1·82	4·55	5·55	−3·73	3·85	2·8	31·5	15·7	−16·4	+0·7	26·2	—	—	—	—	—
1·2	3·0	3·66	−2·46	2·52	0·14	1·02	0·56	−0·48$_5$	−0·07$_5$	0·86	0·137	0·133	0·55	−0·48	−0·07
0·6	1·5	1·83$_5$	−1·23$_5$	1·26	0·04$_5$	0·37$_5$	0·2	−0·18$_5$	−0·01$_5$	0·31	0·12	0·133	0·14	−0·12	−0·02
3·2	4·0	5·9	−2·7	3·59	1·0	6·53	3·22	−3·8	+0·58	5·75	—	—	—	—	—
2·4	3·0	4·43	−2·03	2·7	0·4	1·49	0·91	−0·71	−0·20	1·35	0·268	0·267	0·66	−0·51	−0·15
1·6	2·0	2·95	−1·35	1·70	0·15	0·56	0·34	−0·26$_5$	−0·07$_5$	0·50	0·268	0·267	0·29	−0·23	−0·06
1·2	1·5	2·22	−1·02	1·35	0·08$_5$	0·31	0·19	−0·14$_5$	−0·04$_5$	0·28	0·274	0·267	0·17	−0·13	−0·04
3	2	4·0	−1·0	2·16	0·31	0·66	0·47$_5$	−0·35	−0·12$_5$	0·7	0·47	0·5	0·44	−0·29	−0·15
2·2$_5$	1·5	3·0	−0·75	1·62	0·21$_5$	0·45	0·33	−0·23$_5$	−0·09$_5$	0·48	0·475	0·5	0·25	−0·16$_5$	−0·08
4	1·5	4·9$_5$	−0·4$_5$	2·45	0·35	0·35	0·40$_5$	−0·22$_5$	−0·17$_5$	0·57	1·0	1·0	0·57	−0·32	−0·25
3	1	3·3	−0·30	1·63$_5$	0·25	0·26	0·29	−0·18$_5$	−0·10$_5$	0·42	0·96	1·0	0·25	−0·14	−0·11
6·7$_5$	2·25	7·43	−0·67	3·67	2·0	2·67	2·42	−2·43	+0·01	3·95	—	—	—	—	—

Principal Creep Rates based on equations

$$\left[A + D_1\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{8} + D_2\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{25}\right]$$

$\times[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)]$	$\times[(\sigma_2-\sigma_3)-(\sigma_1-\sigma_2)]\ \times$	$[(\sigma^3-\sigma_1)-(\sigma_2-\sigma_3)]$
	$\times\ 10^6$/hr.	
—	—	—
—	—	—
110	−110	0
7·6	−7·6	0
1·85	−1·85	0
0·77	−0·77	0
—	—	—
—	—	—
—	—	—
—	—	—
—	—	—
—	—	—
0·57	−0·37$_5$	−0·19
—	—	—
—	—	—
—	—	—
	where $A = 2{\cdot}55 \times 10^{-8}$ $D^1 = 0{\cdot}5 \times 10^{-20}$ $D^2 = 2{\cdot}5 \times 10^{-72}$	

as suggested by Bailey, were representative of existing experimental results (F is here a function). It was noted that the two varieties of equation mentioned were special cases of the very general equations :

$$E = f(J_2, J_3^2)\left[p(J_2, J_3^2)\, J_3\, (S^2 - {}^2/_3 J_2 I) + q\,(J_2, J_3^2) S\right]$$

as advanced by Prager.

It is, of course, possible that the function F be of other form than a power function—e.g., it may be of the nature :

$$e^{\left[\Sigma(\sigma_1-\sigma_2)^2\right]}$$

Thirdly, equations of the type :

$$C_1 = A\left[e^{C(\sigma_1-\sigma_2)^n} - e^{C(\sigma_3-\sigma_1)^n}\right] \quad \text{etc.}$$

are possible, but these appear to lead to certain inconsistencies associated with the case of pure tension.

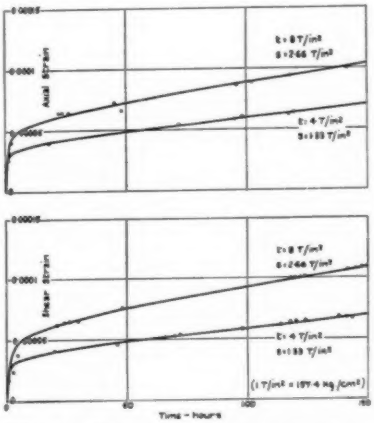

Fig. 6.—Creep strain-time curves for stress system t/s = 3/1 at 150° C.

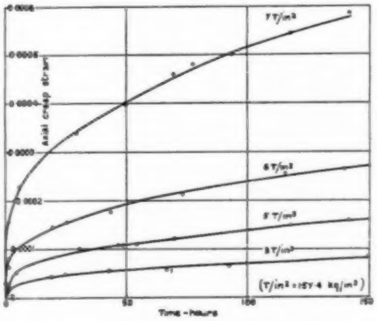

Fig. 7.—Creep strain-time curves under pure tensile stresses at 200° C.

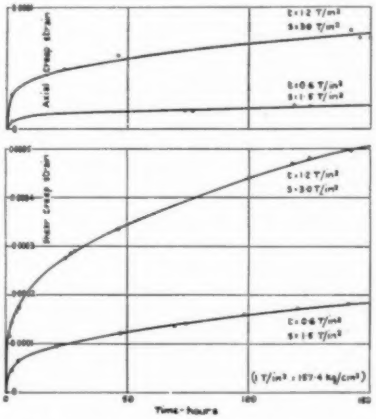

Fig. 8.—Creep strain-time curves under stress system t/s = 0·4 at 200° C.

All Creep Rates Measured at 150 hours

Principal Creep Rates based on equations

$$C_1 = \left\{A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0\cdot5} + B\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{13\cdot5}\right\} \times\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{where } A = 0{\cdot}74_5 \times 10^{-8},\ B = 2{\cdot}55 \times 10^{-35}$$

$\times\ 10^{-6}$/hr.
12·8
1·3
0·76
0·52$_5$
0·34
0·19
23·0
1·05
0·5
0·34
0·22
15·5
0·55
0·14
3·93
0·66
0·29
0·17
0·44
0·25
0·57
0·25
6·6

Further the equations of Kanter :

$$C_1 = K\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]e^{C\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]} \quad \text{etc.}$$

were mentioned in the introduction, and the objection to them stated.

It appears, therefore, that some means must be adopted to discriminate between the above-mentioned equations, to decide which particular variety fits best the experimental results.

One satisfactory means of comparison* appears to be upon the basis of the shear stress and strain in the octahedral planes. The stress strain system in these planes (which coincide with the faces of a regular octahedron having axes coinciding with the principal axes of stress and strain) is such that the strain is pure shear strain, normal strain being absent, and the normal stress being simply $\Sigma\,\sigma_1/_3$—i.e., the hydrostatic component of the stress system which does not cause distortion. The normal strain is actually $\Sigma\,\epsilon_1/3$ which vanishes under conditions of plastic or creep strain.

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* Cf. Ref. 8, Bibliography.

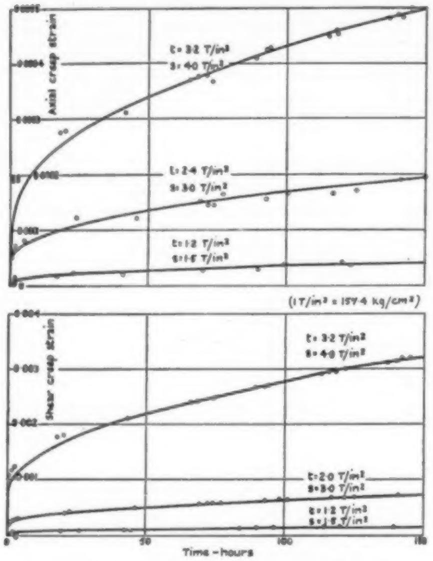

Fig. 9.—Creep strain-time curves under stress systems t/s = 0·8 at 200° C.

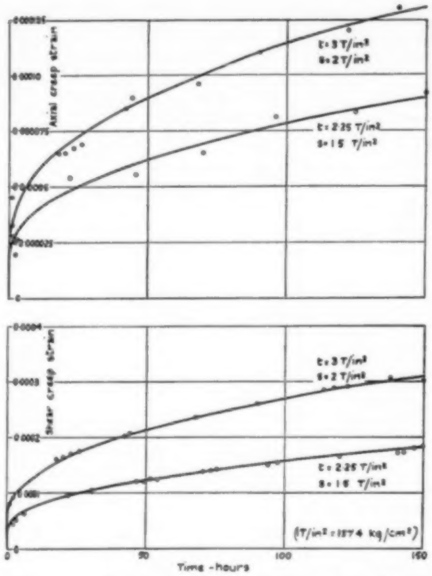

Fig. 10.—Creep strain-time curves under stress systems t/s = 1·5 at 200° C.

Moreover in magnitude the shear strain in these planes is proportional to the "resultant" of the maximum shear strains, or the distortional strains, and therefore can be looked upon as the "resultant" creep of the stress system, and the shear stress produced proportional to the resultant of the maximum shear stresses—i.e., to the distortional strain energy of the stress system or "resultant" distortional stress. A consideration of the octahedral stress and strain would, therefore, appear to offer a comparison of the system in a most general form.

Finally, any plot of functions of octahedral stress against octahedral strain, offers a direct means of testing the applicability of assumption (4) of the introduction, since if this assumption be applicable, octahedral stress-strain points for all stress systems will fall on one continuous curve.

Accordingly for the results at 150° C., plots were made of various functions of octahedral shear stress against either the octahedral shear creep rate, or of the ratio of octahedral shear creep rate to octahedral shear stress. These plots illustrated the applicability or otherwise of various types of creep rate-stress relations. In view of the appreciable number of these plots it has been thought necessary only to illustrate the plot which most reasonably and simply represented the results.

This particular plot appeared to be that of log octahedral stress σ_o, against log octahedral creep rate C_o, and is shown in Fig. 12. It is seen that the experimental points corresponding to the various stress systems† are reasonably well disposed around one general curve, thus indicating that the Hencky theory, which postulates that the octahedral strain is a function of the octahedral stress of the system, is a reasonably good approximation at this temperature. The curve of Fig. 12 is closely linear in its lower range of stress, and therefore suggests that for this material and temperature the dependence of creep rate on stress is of the nature of a power function for low and moderate stresses. At higher stresses it is obvious that a more complex relation exists.

Dealing for the moment with the lower range of stresses, it will be observed that the general type of principal plane equations which correspond with a power function relation of creep rate to stress is :

$$(1)\ C_1 = A\left[(\sigma_1-\sigma_2)^2\right]^m\left[(\sigma_1-\sigma_2)^n-(\sigma_3-\sigma_1)^n\right]\quad \text{etc.}$$

where n may = 1 or m = 0.

The octahedral stress and strain corresponding to these equations are, of course, given by the relations :

$$\sigma_o = {}^1/_3\ \sqrt{(\sigma_1-\sigma_2)^2}$$

$$C_o = {}^2/_3\ \sqrt{(C_1-C_2)^2}$$

It will be observed that the linear curve in Fig. 12 has a slope of unity, and is therefore the octahedral plot

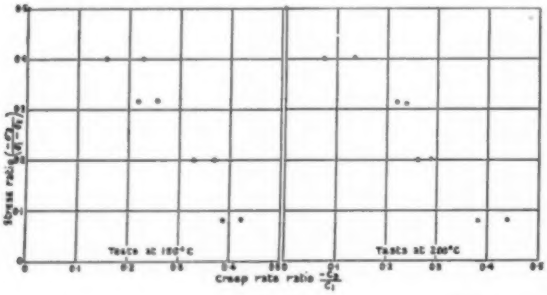

Fig. 11.—Relations between stress ratio $\dfrac{-\sigma_3}{\sigma_1-\sigma_2}$ and creep rate ratio $\dfrac{-C_3}{C_1}$

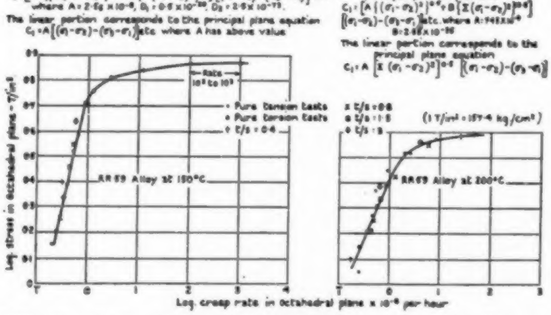

Fig. 12.—Log. stress—log. creep rate curve for the Octahedral plane.

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† i.e., over the stress range in which tests of all types were made.

computed by means of the two equations just mentioned from principal plane equations of type :

$$C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

Thus for low and moderate stresses in this material at this particular temperature, the experimental results are well represented by the most simple form of St. Venant type equation, and the maximum principal shear strains are actually proportional to the maximum principal shear stresses. Reference to Appendix 3 will show that on theoretical grounds an isotropic material obeying the Hencky criterion would be expected if showing a relation of general type (1) to conform with the value of $n = 1$ or 5. At 150° C. the experimental results check this theoretical proposition.

The actual equation and value of A to give the best general fit of results is given in Fig. 12.

Turning now to consider the high stress range at 150° C., and observing the general features of the curve, it will be noted that after a transition range of stress there is a comparatively abrupt change of curvature, and the rate of creep increases very rapidly with increasing stress, increasing, in fact, by a hundred to one ratio with a rise of only about one-half ton per sq. in. or thereabouts.

The above remarks appear to indicate that including the initial linear curve, three regions of stress-creep rate relations exist, and that therefore a general equation expressing the stress-creep rate relations for the whole stress range might well be the sum of three functions. Actually analysis indicated this to be the case. The stress creep-rate relations were analysed on the basis of the assumption that the creep rate could be expressed in terms of the sum of power functions of stress, as was also assumed, for example, in the case of the derivation of Prager's equations.

This analysis indicated that the mean curve could be well represented by a sum of three power functions of stress, and it was found possible to form such an equation in accordance with the basic assumptions of the St. Venant-Von Mises type of equation by the principal plane form :

$$C_1 = \left[A + D_1\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m} + D_2\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]$$
$$\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

where A, D_1, D_2, m_1 and m_2 are constants.

The actual equation and values of A_1, D_1, D_2, m_1 and m_2, are given in Fig. 12. At moderate and low stresses all except the initial term in the first bracket become negligible.

It is, of course, to be understood that the above equation is subject to modification by virtue of any anisotropy occurring at high combined stresses. If this anisotropy were of the type occurring at 200° C., and discussed in a subsequent paragraph, the modification would be in the values of C_2 and C_3, but not in C_1. Actually the type of anisotropy exhibited at 200° C. in combined stress tests has characterised this type of test at high stresses for a number of materials within the experience of the author and there is every reason to believe that combined stress tests at 150° C. would have shown this trait. Apparently, therefore, for the present material at 150° C., while at low and moderate stresses creep results from shear on planes capable of contributing to creep, at higher stresses the creep can only be adequately described by terms emphasising the increasing importance of the effect of the general stress system on the creep as the stress increases. R. W. Bailey has suggested that under such circumstances the applied stress virtually coincides with the " yield " stress of the material.

It is to be noted at this stage that no attempt has been made to determine the creep rate-time relations. Any adequate understanding of creep rate-time relations must involve knowledge of the third phase of the creep curve, and any equations based only on a knowledge of the primary and secondary stages must necessarily be of an approximate nature.

Again, neither plain tensile creep data nor torsion creep data carried into the third phase of creep would be adequate for this purpose, since there is every reason to regard the geometrical form of the creep curve in relation to time as independent of the actual nature of the imposed stress system. The above remarks apply equally to the work at 200° C. Accordingly any consideration of creep-strain time functions will be left to a future paper devoted entirely to this subject.

Before leaving consideration of the creep rate-stress relations attention is drawn to Appendix 1. In that Appendix it is shown that if the creep rate-stress relations are of the general type :

$$C_1 = A\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

where A may be an invariant of the stress system, then the relation $C_a/C_c = {}^t/_{3s}$ holds true.

If, however, $\quad C_1 = A\left[(\sigma_1-\sigma_2)^n-(\sigma_3-\sigma_1)^n\right]$

where n is greater than 1, the relation becomes :

$$C_a/C_c = 1/4a\left[\frac{\{(1+b)^n+(1-b)^n\}\,b}{\left[2^{n+1}b^n+(1+b)^n-(1-b)^n\right]}+1\right]$$

where $a = {}^s/_t$ and $b = \sqrt{1+4a^2}$.

In Table I the values of C_a/C_c and ${}^t/_{3s}$ are given, and it is seen that apart from the single value at ${}^t/_{3s} = 0{\cdot}133$, the average difference of the ratios of C_a/C_c from ${}^t/_{3s}$ is only 0·9%. Thus no evidence is presented which definitely suggests that a value of n equal to unity is unsuitable.

The preceding remarks of this paragraph have indicated that equations based on the St. Venant theory give very reasonable representation of the experimental results at this temperature.

Lode[13] examined the application of this type of equation to experimental results on a number of materials in a very simple manner by computing the experimental values of two variables μ and v. In the nomenclature of the present test where $\sigma_1 > \sigma_3 > \sigma_2$.

$$\mu = \frac{2(\sigma_3-\sigma_2)}{(\sigma_1-\sigma_2)} - 1$$

$$v = \frac{2(C_3-C_2)}{(C_1-C_2)} - 1$$

If the original St. Venant relations, or modified St. Venant relations are valid, the μ, v, curve should be a straight line at 45° to the axes of μ and v.

In Fig. 13 the experimental points for 150° C. are plotted for the several stress systems involved, each

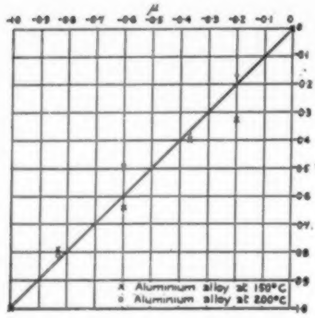

Fig.13.—Relation between

$$\mu = 2\ \frac{(\sigma_3-\sigma_2)-1}{(\sigma_1-\sigma_2)}\quad v = \frac{2\,(C_3-C_2)-1}{(C_1-C_2)}$$

where σ_3 = O in all tests.

plotted point representing the average of two or three tests taken from the whole of the stress range. It will be seen that these points are well disposed around a line drawn at 45° to the axes of μ and v. This diagram thus gives additional supporting evidence in favour of the use of expressions based on St. Venant theory to represent experimental results.

(*b*) *Relations between applied stresses to give specific octahedral creep rates at* 150° *C.*

An interesting relation holds between applied tensile and torsion stresses required to produce specific creep rates in the octahedral plane, for a material which obeys the Von Mises-Hencky criterion of plastic strain, and in which therefore octahedral plane creep rate is an explicit function of octahedral stress.

This relation is obtained in Appendix 2, where it is shown that for any complex stress system consisting of simple tension t, and simple torsion s, the relation between these two stresses to produce specific octahedral creep rate is always such that :

$$\frac{t^2}{T^2} + \frac{s^2}{S^2} = 1$$

where T is the pure tensile, and S the pure torsion stress, which acting alone would produce the specific octahedral creep rate. Also it is shown that :

$$T = \sqrt{3}\,S,$$

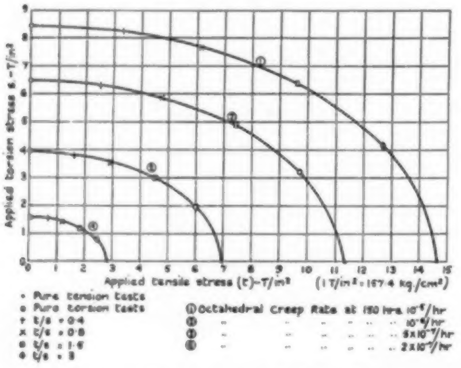

Fig. 14.—Relations between applied tensile stress (t) and applied torsion stress (s), to produce specific creep rates in the octahedral plane.

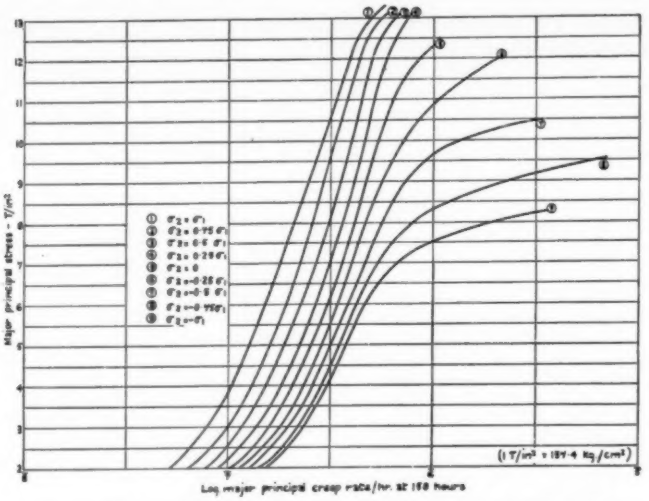

Fig. 16.—Major principal stress—major principal creep rate relations for various values of the minor principal stress, and based on the equation :

$$C_1 = \left[A + D_1\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{5} + D_2\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{25}\right]\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

where $A = 2\cdot 55\times 10^{-8}$, $D_1 = 0\cdot 5\times 10^{-20}$, $D_2 = 2\cdot 5\times 10^{-78}$, $\sigma_3 = O$

thus the expression just noted may be written :

$$t^2 + 3s^2 = T^2,$$

$$\text{or } \frac{t^2}{3} + s^2 = S^2$$

These relations are obviously elliptical.

It can thus be seen that provided the material follows the Hencky criterion, the applied tension and torsion stresses corresponding to a particular stress system required to produce a specific octahedral creep rate may be written down from a knowledge of either the pure torsion or the pure tensile creep characteristics of the material. This is true throughout the whole stress and creep rate range, and is a relation quite independent of the nature of the stress creep-rate relation. It is to be emphasised, however, that this relation applies only to octahedral creep rates, and is not true of principal creep rates.

It may further be noted that if in the case of any particular new material, the two assumptions are made :

1. That the material obeys the Hencky criterion of plastic strain.
2. That ${}^{t}/_{3s} = C_a/C_c$.

then octahedral creep rates can be expressed in terms of axial or shear creep rates, and it is thus possible to estimate C_a and C_c corresponding to particular values of applied tension and torsion from pure tensile creep and pure torsion creep data. This is obviously a useful practical matter, but owing to the nature of the assumptions (1) and (2) either of which may be departed from in general, it can only be an intelligent forecast of the truth, except in the case of new members of general classes of material where one member of the class has been shown to obey both of the above assumptions, or alternatively assumption (1) combined with the relation :

$$\frac{C_a}{C_c} = 1/4a\left[\frac{\left\{(1+b)^n + (1-b)^n\right\}\ b}{\left[\ 2^{n+1}b^n + (1+b)^n - (1-b)^n\ \right]} + 1\right]$$

In Fig. 14 for the temperature of 150° C., the relation between t and s for a number of specific octahedral

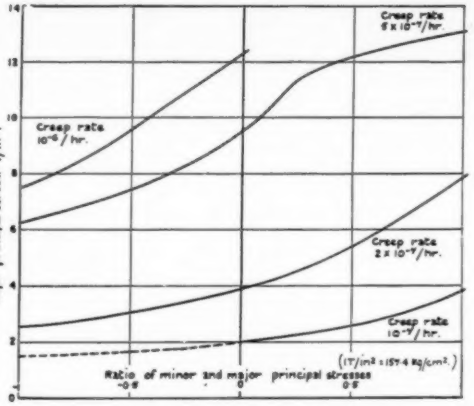

Fig. 18.—Major principal stresses to give various specific creep rates at 150 hours for several ratios of minor to major principal stresses (the third principal stress being zero).

creep rates is plotted. It will be seen that the points lie on smooth quadrants of ellipses. Other quadrants of the ellipse would be involved for tension and torsion strain of reversed sign.

(c) *Values of major principal creep rates for specific values of major principal stresses at 150° C.*

From the point of view of the designer it is obviously of considerable interest to have information available giving for a range of major principal stresses, the major principal creep rates with various values, both negative and positive of one secondary principal stress, the other secondary principal stress being zero in all cases.

In Fig. 16, therefore, for a range of values of the major principal stress σ_1, combined with minor principal stress σ_2, having values of σ_2 ranging from $\sigma_2 = \sigma_1$, through $\sigma_2 = 0$ to $\sigma_2 = -\sigma_1$, and also having in all cases $\sigma_3 = 0$, the log major principal creep rate is plotted, being computed from the experimentally derived equation.

$$C_1 = \left[A + D_1 \left\{ \Sigma (\sigma_1 - \sigma_2)^2 \right\}^5 + D_2 \left\{ \Sigma (\sigma_1 - \sigma_2)^2 \right\}^{25} \right]$$
$$\left[(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1) \right]$$

where $A = 2 \cdot 55 \times 10^{-8}$, $D_1 = 0 \cdot 5 \times 10^{-20}$, $D_2 = 10^{-73} \times 2 \cdot 5$.

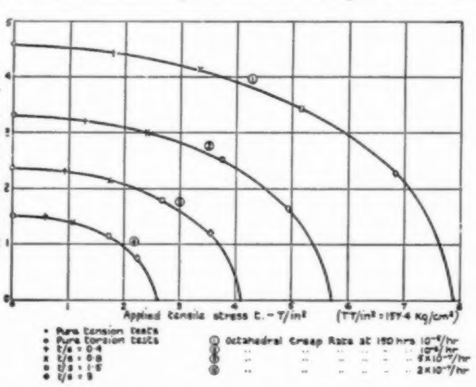

Fig. 15.—Relations between applied tensile stress (t) and applied torsion stress (s), to produce specific creep rates in the octahedral plane.

It is to be noted, of course, that this diagram may be used to compute major principal creep rates for stress systems in which σ_3 is not zero, since the addition or subtraction of a hydrostatic stress to a system does not affect the creep characteristics of the system. Thus the system σ_1, σ_2, σ_3, is equivalent precisely to the system $(\sigma_1-\sigma_3)$, $(\sigma_2-\sigma_3)$, O, and gives rise to the same values of C_1 upon insertion into the equations above.

(d) *Values of major principal stresses to give a specific major principal creep rate when combined with various values of secondary and minor principal stress σ_2 (the third principal stress being zero) at 150° C.*

Evidently from Fig. 16 by interpolation of values of σ_1 along the ordinates intersecting the horizontal axis at some specific value of the major principal creep rate ; a series of curves may be obtained giving for a series of ratios σ_1/σ_2, the values of σ_1 corresponding to a given specific major principal creep rate. These curves again should be of considerable use to designers and are presented in Fig. 18.

Consideration of the Behaviour of the RR.59 Alloy at 200° C.

(a) *Experimental creep rate-stress relations considered in relation to various theories at 200° C.*

In the paragraph relating to the consideration of creep rate-stress relations at 150° C., the various possible types of relation arising out of various theoretical considerations were discussed, and also the means of choosing the most appropriate type of equation to represent the experimental results. All the remarks in that paragraph apply equally to tests at 200° C.

Again at this temperature it was found that the most simple and representative plot was of log octahedral stress σ_o against log octahedral creep rate C_o. This plot is shown in Fig. 12 which shows that the experimental points are well disposed around a mean curve, indicating that at this temperature, as at 150° C., the creep of the material closely obeys the Hencky criterion of plastic strain.

It will be noted that at moderate and low ranges of stress, the log stress-log creep rate relation is linear, thus indicating the dependence of the creep rate upon a simple power function of stress. At higher stresses the curve departs from linearity, and a more complex relation between stress and strain must arise. It is seen, however, that at 200° C. the transition from linearity to non-linearity is somewhat smoother than in the case of the corresponding curve at 150° C., and moreover occurs at considerably lower stresses. Of course, tests at still higher stresses than were used might have shown an abrupt " yield " similar to that noted at 150° C.

Dealing in the first instance with the moderate and lower ranges of stress, it will be recalled that the linear log stress-log creep rate curve obtained over these stress regions must be associated with a principal plane curve of general type :

$$C_1 = A \left[\Sigma (\sigma_1 - \sigma_2)^2 \right]^m \left[(\sigma_1 - \sigma_2)^n - (\sigma_3 - \sigma_1)^n \right]$$

where n may = 1 or m = O, from which equations octahedral plane equations may be computed by means of the two equations :

$$\sigma_0 = {}^1/_3 \sqrt{(\sigma_1 - \sigma_2)^2} \text{ and } C_o = {}^2/_3 \sqrt{(C_1 - C_2)^2}$$

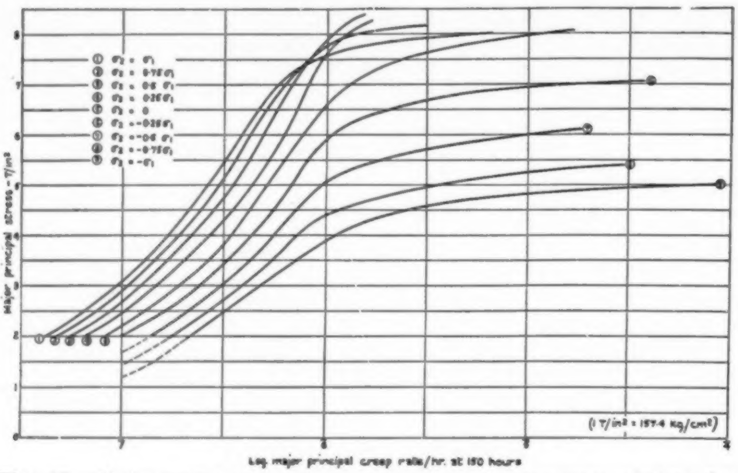

Fig. 17.—Major principal stress—major principal creep rate relations for various values of the minor principal stress and based on the equation:

$$C_1 = \left[A\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{0\cdot5} + B\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{13\cdot5}\right]\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$
where $A = 0{\cdot}74_5 \times 10^{-8}$, $B = 2{\cdot}55 \times 10^{-35}$, $\sigma_3 = O$.

It will be observed that the linear curve in Fig. 12 has a slope of 2, and may therefore be the octahedral plot corresponding to a principal plane relation of the type:

$$C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0\cdot5}\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \quad \text{etc.}$$

which is the St. Venant-Von Mises type of equation as originally put forward by Odquvist, Marin and Soderberg. The actual value of A for the best general fit of results is given in Fig. 12.

Again if reference be made to Appendix 1 it will be noted that theoretical considerations indicate that an isotropic material obeying the Hencky criterion, and having a creep rate-stress relation of the general type shown would be expected to give n = 1 or 3.

Considering now creep rate-stress relations in the higher stress ranges at 200° C. there definite departure from linearity occurs, but from Fig. 12 it may be observed that the experimental points are still well disposed around the curve, in other words the Hencky criterion is well fulfilled at these stresses. The transition from linearity to non-linearity is quite smooth, which fact tends to suggest that the whole curve up to the magnitudes of stress concerned might well be represented by a double function relation. Analysis carried out on the assumption that the creep rate might well be represented by the sum of power functions of stress, indicated that terms of two orders were sufficient for this purpose, and the curve shown in Fig. 12 is the plot of log octahedral stress against log octahedral creep rate corresponding to principal plane equations of the type:

$$C_1 = \left[A\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_1} + B\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

The actual equation and values of A, B, m_1 and m_2 for the best general fit of results are shown in Fig. 12.

However, despite the fact that the octahedral plane equivalent of the equation noted above fits well the experimental points in Fig. 12, examination of the results given in Table II indicates that at one or two of the higher stresses the wall thickness creep is positive indicating anisotropy, the major and minor rates in these tests are almost equal but opposite in sign while the wall thickness creep tends to a value of zero. The material appears to behave as though the direction of wall thickness hardened considerably more than the other two directions. It may here be stated that the author has had experience of the behaviour of several materials at various temperatures under relatively high combined stresses, and in all cases the type of anisotropy noted here has occurred if sufficient plastic strain takes place upon loading. In all these materials no axial creep rate was noted in pure torsion tests whatever the order of stress. It is suggested that this anisotropy may have arisen from preferential strain hardening occurring upon loading the specimen, due to the relatively large plastic strain arising upon loading at these high stresses, and possibly in a secondary degree to the difficulty of ensuring that increments of tensile and torsion load should be added absolutely simultaneously, and with equal freedom from impact effects. In the case of the present material no axial creep occurred in any pure torsion test, and the wall thickness and diametral creep were half the longitudinal in the highest stress tensile test at 200° C. These facts indicate that no evidence of anisotropy occurred in either the pure torsion or pure tension tests.

Returning to the combined stress creep tests it appears that high initial plastic strain results in behaviour which in effect approximates to that of a pure torsion test in which the principal axes of strain are those of principal stress in the combined stress test. This fact offers an explanation of the isotropic behaviour in the pure torsion test since if the result of the high initial plastic strain in the combined stress tests is to make subsequent behaviour tend towards that of a pure torsion test, then the pure torsion test being the limiting case might remain unaltered in isotropic characteristics as observed in the current and other test. The physical reason behind this phenomenon is not at the moment apparent. However, a survey of results for the current and other materials indicates that in general the high combined stress tests can be represented by equations of the form:

$$C_1 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

$$C_2 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[B_1(\sigma_2-\sigma_3) - (\sigma_1-\sigma_2)\right]$$

$$C_3 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_3-\sigma_1) - B_1(\sigma_2-\sigma_3)\right]$$

where B_1 exceeds unity.

It is to be noted that C_1 remains the same as in the case of isotropy, $C_1 = O$ for all systems, and for pure tension C_1, C_2 and C_3, are as in the case of isotropy.*

In general, B_1 varies with the stress system imposed, but has some value for various arithmetical values of

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* This accounts for the isotropic behaviour in the pure tension test.

σ_1, σ_2, in a given system, and would apparently have the value of unity for pure torsion. It is necessary to draw the conclusion that the anisotropy occurring is not independent of the imposed stress system, although conforming to the general type indicated above. This appears to strengthen the suggestion that the state of anisotropy is imposed by the relatively high initial plastic strain. In the case of the present material at 200° C., a plot is made in Fig. 20 showing the relation between values of B_1 and $^t/_s$, for values of the latter between 0 and 3. It is noted that above $^t/_s = 0{\cdot}4$ the relation is roughly linear.

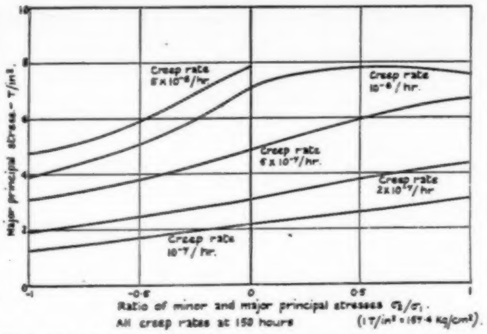

Fig. 19.—Major principal stresses to give various specific creep rates for several ratios of minor to major principal stresses (the third principal stress being zero).

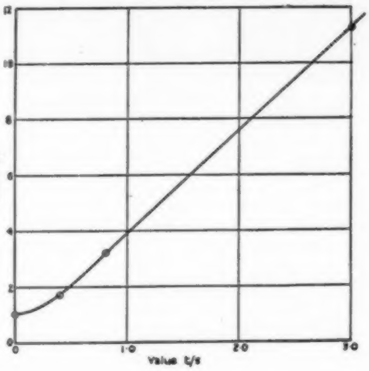

Fig. 20.—Variation of the value factor B_1 in the equations :

$C_1=F\left[(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$, $C_2=F\left[(\sigma_1-\sigma_2)^2\right]\left[B\,(\sigma_2-\sigma_3)-(\sigma_1-\sigma_2)\right]$, $C_3=F\left[(\sigma_1-\sigma_2)^2\right]\left[(\sigma_3-\sigma_1)-B_1(\sigma_2-\sigma_3)\right]$ **with value of t/s.**

If the anisotropy shown be due to the initial plastic strain as suggested, then there are thus reasonable grounds for suggesting that at that temperature the "natural" creep of the material might be well represented by equations of the type :

$$C_1 = \left[A\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{m_1} + B\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]$$

$$\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right] \qquad \text{etc.}$$

It was noted in the paragraphs dealing with creep rate-stress relations at 150° C., that for an isotropic material obeying creep rate stress relations of type :

$$C_1 = A\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ the relations } {C_a}/{C_c} = t/3s$$

held, while for material obeying the relations :

$$C_1 = A\left[(\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n\right]$$

the relation held

$$\frac{C_a}{C_c} = 1/4a\left[\frac{\left\{(1+b)^n + (1-b)^n\right\}\,b}{\left[2^{n+1}\,b^n + (1+b)^n - (1-b)^n\right]} + 1\right]$$

$$\text{where} \quad a = {^s/_t} \text{ and } b = \sqrt{1+4a^2}$$

The applicability of the relations is indicated in Table II for all except those tests in which anisotropy was indicated by the positive nature of wall thickness creep ; with the following results.

In Table II the values of C_a/C_c and t/3s are given and it will be found that the average difference from the theoretical value corresponding to equations :

$$C_1 = A\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \quad \text{and etc.}$$

obtained over this region of stresses is thus about 2%. Obviously no stray evidence of departure from relations of the above type is given by this comparison.

Again at 150° C., evidence supporting the use of equations based on the St. Venant relations may be obtained by consideration of the plot shown in Fig. 13 of the Lode variables μ and v for the stress systems involved in the experimental work at 200° C. The plot is confined to experimental results taken from the region covered by the linear portion of the curve in Fig. 12. It will be seen that for this region the experimental points are well disposed around a line at 45° to the axes of μ and v, as would be expected if relations of the modified St. Venant type were applicable.

(*b*) *Relations between applied stresses to give specific octahedral creep rates at* 200° *C.*

In Fig. 15 for 200° C. the relations between t and s for all experimental stress systems, to give a number of specific octahedral creep rates are shown. As at 150° C. the experimental points lie smoothly on an ellipse.

Values of Major Principal Creep Rates for Specific Values of Major Principal Stresses at 200° C.

In Fig. 17 for a range of values of the major principal stress σ_1, combined with minor principal stress σ_2, having values of σ_2 ranging from $\sigma_2 = \sigma_1$, through $\sigma_2 =$ O, to $\sigma_2 = -\sigma_1$, and also having in all cases $\sigma_3 =$ O, the log major principal creep rate is plotted, being computed from the experimentally derived equation :

$$C_1 = \left[A\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{0\cdot5} + B\left\{\Sigma\,(\sigma_1-\sigma_2)^2\right\}^{13\cdot5}\right]$$

$$\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

where $\quad A = 0{\cdot}74_5 \times 10^{-8}$, and $B = 2{\cdot}55 \times 10^{-35}$.

Derived curves showing values of major principal stresses to give a specific major creep rate when combined with various values of secondary and minor principal stress σ_2 (the third principal stress being zero) and shown for 200° C. in Fig. 19.

General Conclusions

1. At 150° and 200° C. the material behaved isotropically over a range of moderate and lower stresses. At 200° C. combined stress tests in higher regions of stress showed some anisotropy, which may possibly have arisen as the results of the considerable initial plastic strain at such higher stresses. Combined stress tests were not made at high stresses at 150° C., but had this

been done it is possible that anisotropy similar to that at 200° C. would have been shown.

2. Over the whole stress range investigated the material appeared to obey the Hencky, or shear strain energy criterion of plastic strain.

3. At moderate and low stresses the creep rate-stress relations were well represented at 150° C. by equations of the type :

$$C_1 = A\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc., and at } 200^\circ \text{ C. by}$$

$$C_1 = A\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{0\cdot 5}\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

4. Over the whole range of stress the creep rate-stress relations appeared to be based at 150° C. on general equations of the type :

$$C_1 = \left[A + D_1\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_1} + D_2\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right] \text{ etc.}$$

and at 200° C. on equations of the type :

$$C_1 = \left[A\left\{(\sigma_1-\sigma_2)^2\right\}^{m_1} + B\left\{\Sigma(\sigma_1-\sigma_2)^2\right\}^{m_2}\right]\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$

At moderate and low stresses the above equations deteriorate into the equations given under (3) above.

5. The anisotropy occurring at high stresses in the combined stress tests was such in all cases as to tend to equalise the values of major and minor creep rates and to render wall thickness creep approximately zero (this, of course, is the state of affairs in a pure torsion test). These conditions can be represented by equations of the general type.

$$C_1 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_1-\sigma_2) - (\sigma_3-\sigma_1)\right]$$
$$C_2 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[B_1(\sigma_2-\sigma_3) - (\sigma_1-\sigma_2)\right]$$
$$C_3 = F\left[\Sigma(\sigma_1-\sigma_2)^2\right]\left[(\sigma_3-\sigma_1) - B_1(\sigma_2-\sigma_3)\right]$$

where B_1 is dependent on the applied stress system, and exceeds unity in all cases except pure torsion. The above equations correspond with the state of isotropy for pure tension which is in accordance with experimental facts.

6. If a material obeys the Hencky criterion of plastic strain, and exhibits a linear log stress-log creep rate relation in pure tension, or pure torsion creep, then the principal, axial and shear creep rates under any combined stress system may be computed directly from knowledge of the pure tensile or pure torsion creep characteristics only.

Appendix 1

The theoretical relation between the ratio C_a/C_e and $^t/_s$ for creep conditions.

We have

(*a*) $C_1 = C_a + C_e/2\left(\sqrt{(t/2s)^2+1} - t/2s\right)$

(*b*) $C_2 = C_a - C_e/2\left(t/2s + \sqrt{(t/2s)^2+1}\right)$

(*c*) $C_3 = C_e\, t/2s - 2C_a$

(*d*) and the equations $C_1 = A\left((\sigma_1-\sigma_2)^n - (\sigma_3-\sigma_1)^n\right)$ etc.

where A may be an invariant of the system.

From (*a*) and (*b*)

$$(C_1-C_2) = C_e\left(\sqrt{(t/2s)^2+1}\right) = C_e\,\frac{(\sigma_1-\sigma_2)}{2s}$$

since $\begin{matrix}\sigma_1\\ \sigma_2\end{matrix} = {}^t/_2 \pm \frac{1}{2}\sqrt{t^2 + 4_s^2}$

Thus $C_e = \frac{2s\,(C_1-C_2)}{(\sigma_1-\sigma_2)}$

also $C_a = \frac{-C_3}{2} + C_e\, t/4s$

$$\frac{C_a}{C_e} = \frac{t}{4s} - \frac{C_3}{4s}\,\frac{(\sigma_1-\sigma_2)}{(C_1-C_2)} = \frac{t}{4s} + \frac{(C_1+C_2)}{(C_1-C_2)}\,\frac{(\sigma_1-\sigma_2)}{4s}$$

$$= \frac{t}{4s} + \frac{(\sigma_1^n + \sigma_2^n)(\sigma_1-\sigma_2)}{(2(\sigma_1-\sigma_2)^n + \sigma_1^n - \sigma_2^n} \times 1/4s$$

If we make $^s/_t = a$, and $\sqrt{1 + 4_a^2} = b$

this becomes $\frac{C_a}{C_e} = 1/4a\left[\frac{\{(1+b)^n + (1-b)^n\}\; b}{\left[2^{n+1}b^n + (1+b)^n - (1-b)^n\right]} + 1\right]$

If $n = 1$ this simplifies to $C_a/C_e = t/3s$.

Appendix 2

The relation between the applied tensile stress t, and the applied torsion stress s for specific octahedral creep rate.

Plotting of experimental results indicates that the octahedral creep rate is a unique function of the octahedral stress. Thus for all combinations of t and s for a specific octahedral creep rate there must be a unique value of the octahedral stress $= {}^1/_3\sqrt{\Sigma(\sigma_1-\sigma_2)^2}$. This corresponds to differing values of σ_1, σ_2, t and s for each stress system. If $\sigma_3 = O$ we have :

$$\begin{aligned}\sigma_1 &= {}^t/_2\,(1 + \sec 2\phi)\\ \sigma_2 &= {}^t/_2\,(1 - \sec 2\phi)\\ (\sigma_1-\sigma_2) &= t\sec 2\phi\\ \text{and } \Sigma(\sigma_1-\sigma_2)^2 &= t^2/_4\,(6\sec^2 2\phi + 2)\\ &= t^2/_4\left[6(1 + \tan^2 2\phi) + 2\right]\\ &= 2t^2 + 6_s^2\end{aligned}$$

The octahedral shear stress :

$$= \frac{\sqrt{2}}{3}\sqrt{t^2 + 3s^2}$$

$$= \sqrt{\frac{2}{3}}\,t\left(\sqrt{1 + 3a^2}\right)$$

where $s/t = a$

Thus if the value of the octahedral stress = K, for any specific octahedral creep rate, the operative t and s are as follows :

$$t = \frac{3K}{\sqrt{2(1 + 3a^2)}},\ \text{and } s = \frac{3Ka}{\sqrt{2(1 + 3a^2)}}$$

For pure tension $T = \frac{3K}{\sqrt{2}}$. For pure torsion $S = 3K\sqrt{6}$

Then $\frac{t^2}{T^2} + \frac{s^2}{S^2} = \frac{1}{(1 + 3a^2)} + \frac{3a^2}{(1 + 3a^2)} = 1$

Also since $T = \sqrt{3}\,S$, we have

$$\frac{t^2}{T^2} + \frac{s^2}{S^2} = 1 \text{ or } \frac{t^2}{3S^2} + \frac{s^2}{S^2} = 1$$

Thus for corresponding specific octahedral creep rates the relation between t and s is ellipitcal, and this applies throughout the whole range of stresses.

Appendix 3

The nature of the creep rate-stress relations in the case of an isotropic material obeying the Hencky or shear-strain energy criterion of plastic strain.

Suppose the relations are such that the creep rate is a power function of the stress system. In its most simple form let this be :

$$C_1 = A\left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m\left[(\sigma_1-\sigma_2)^n-(\sigma_3-\sigma_1)^n\right]$$

$$C_2 = A\left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m\left[(\sigma_2-\sigma_3)^n-(\sigma_1-\sigma_2)^n\right]$$

$$C_3 = A\left[\tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2\right]^m\left[(\sigma_3-\sigma_1)^n-(\sigma_2-\sigma_3)^n\right]$$

where $\sigma_1 > \sigma_3 > \sigma_2$

and also let the material obey the Hencky shear-strain energy criterion of plastic strain. When this is so, for equal values σ_o of the octahedral shear stress in tension and torsion equal values of the octahedral creep rate γ_o will arise.

Now consider the two cases of tension and torsion :

(1) *Tension* Here let $\sigma_1 = t,\ \sigma_2 = \sigma_3 = O,\ \tfrac{1}{2}\Sigma(\sigma_1-\sigma_2)^2 = t^2$

$$C_1 = At^{2m}\left[2t^n\right] = 2At^{2m+n}$$

$$C_2 = -At^{2m+n}$$

$$C_3 = -At^{2m+n}$$

$$\text{Octahedral stress } \sigma_{ot} = {}^1/_3\left[\Sigma(\sigma_1-\sigma_2)^2\right]^{\frac{1}{2}} = \frac{\sqrt{2}}{3}t$$

$$\text{Octahedral creep } C_{ot} = {}^2/_3\left[\Sigma(C_1-C_2)^2\right]^{\frac{1}{2}} = 2\sqrt{2}\,At^{2m+n}$$

(2) *Torsion* $\sigma_1 = S,\ \sigma_3 = O,\ \sigma_2 = -S.\ \ \tfrac{1}{2}\left[\Sigma(\sigma_1-\sigma_2)^2\right] = 3s^2$

$$C_1 = 3^m S^{2m} A\left[2^n S^n + S^n\right] = 3^m\left[1+2^n\right]A\,S^{2m+n}$$

$$C_2 = 3^m S^{2m} A\left[-2^n S^n - S^n\right] = -3^m\left[1+2^n\right]A\,S^{2m+n}$$

$$C_3 = 3^m S^{2m} A\left[-S^n + S^n\right] = O$$

$$\text{Octahedral stress } \sigma_{os} = {}^1/_3\left[(\sigma_1-\sigma_2)^2\right]^{\frac{1}{2}} = \frac{\sqrt{6}\,S}{3}$$

Octahedral Creep Rate C_{os}

$$= {}^2/_3\left[\Sigma(C_1-C_2)^2\right]^{\frac{1}{2}} = \frac{2\sqrt{6}}{3}C_1$$

$$= 2\sqrt{6}\ 3^{m-1}\left[1+2^n\right]A\,S^{2m+n}$$

For equal σ_o in tension and torsion $s = \dfrac{t}{\sqrt{3}}$

$$\text{and } C_{os} = \frac{2\sqrt{6}\ 3^{m-1}\left[1+2^n\right]At^{2m+n}}{3^{m+n/2}} =$$

$$2\sqrt{2}.3^{-\frac{(n+1)}{2}}\left[1+2^n\right]At^{2m+n}$$

and $C_{ot} = 2\sqrt{2}\,A\,t^{2m+n}$

For application of Hencky theory $C_{os} = C_{ot}$, and these functions can only be equal if n = 1 or 3. Therefore, in the original equation the second term in brackets must be either :

$$\left[(\sigma_1-\sigma_2)-(\sigma_3-\sigma_1)\right]$$

$$\text{or}\ \left[(\sigma_1-\sigma_2)^3-(\sigma_3-\sigma_1)^3\right]$$

$$\text{which in any case} = \left[\Sigma(\sigma_1-\sigma_2)\right]\left[\sigma-\sigma\,)-(\sigma_3-\sigma_1)\right]$$

Acknowledgments

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Plant Reorganisation of British Driver-Harris

British Driver-Harris Co., Ltd., have overcome a rather difficult problem of plant reorganisation. As part of the considerable alterations and extensions to the Company's Manchester factories, the hot mill is to undergo major modifications which will involve a shutdown for about two months, probably July-August. To prevent any possible dislocation in deliveries, the Company have built up a large stock of rod in "Nichrome" and their other alloys. The stock should be sufficient to maintain normal deliveries to every customer.

Those customers who may require in the near future a special type of material, not within the standard range, are being asked to give prior notice of their requirements, so that they can be planned and met before the temporary shutdown.

Reviews of Current Literature

Waste Heat Recovery from Industrial Furnaces

The "Industrial" Waste Heat Recovery Committee of the Publications Committee of the Institute of Fuel; IX + 384 pp., with 112 diagrams and illustrations; price 35s. net. Chapman & Hall, Ltd., London, 1948.

THE importance of waste heat recovery in these times when there is urgent need of conservation of coal, and reduction of costs of production cannot be over emphasized. During the years 1944-5 and 1945-6 at the time when the fuel efficiency campaign sponsored by the Ministry of Fuel and Power had reached the full measure of its stride the national effort was assisted materially by the Institute of Fuel when it encouraged the preparation of a series of papers to be read before that body on two important aspects of fuel efficiency, namely industrial waste heat recovery and industrial insulation. The present volume constitutes a collection of papers read before the Institute on the subject of industrial waste heat recovery. For the reader who is interested in the subject it comprises, therefore, a useful compendium of information on a subject of which there is a voluminous literature, but one not readily accessible to the busy technical man.

In these days so rapid is the advance of the boundaries of technical knowledge that it is a prime but difficult problem of the technologist to keep abreast of even essential information. As the range of literature increases so does the useful material required by any one individual become less accessible in a degree depending on the breadth of the subject. This is a problem which must reach greater proportions in the future. For the present his difficulties in respect of this subject of waste heat recovery have been overcome in the present volume. It is not in any sense a systematic treatise on the subject. From the nature of its origin it cannot be expected to be, for the papers were prepared independently by the various authors, who have in each case dealt with their own special subjects. The subjects covered range from the combustion calculations needed to arrive at a heat balance of a "waste heat" installation and basic data relating to heat transmission, to detailed studies relating to waste heat recovery in specialized industries such as those concerned with carbonisation, metallurgical processes and the manufacture of glass containers.

The fundamental data is presented with clarity and simplicity, though one could have desired that some of the diagrams, particularly those concerned with "simplified heat transfer data," could have been prepared with more consideration for the effects of diagram reduction in the making of printers' blocks. The reading of the letterpress on some of the diagrams is not as simple as it might be.

The names of the authors of the chapters on fundamental data is an earnest of the character and reliability of the information. They are, for example, O. A. Saunders, Margaret Fishenden and P. O. Rosin.

Chapter III comprises a record by T. C. Finlayson and A. Taylor of an exhaustive research carried out by the Woodall-Duckham Companies on regenerator design in its special bearing on carbonisation practice. A further useful review on the conservation of heat in retort settings is to be found in Chapter VI, a contribution by J. G. King and F. I. Dent. Waste heat in metallurgical industry has received the joint attention of no less than six authors, J. A. Kilbey, W. G. Cameron, E. C. Evans, A. H. Leckie, J. L. Harvey and A. E. Balfour, and the subject matter ranges over many different types of plant and practice, from the familiar waste heat boiler, though not as familiar as it might be, to the dry quenching of coke in the iron and steel industry, and to the possible competitive challenge of the gas turbine.

Other subjects which are dealt with are: "Tubular Metalled Recuperators," by G. N. Critchley and H. R. Fehling; "Waste Heat Boilers," by W. Gregson; and "Waste Heat Recovery in the Glass Container Industry," by W. A. Moorshead.

The publishers have produced a clearly printed well illustrated and handy volume. The references are confined to the author's citations, quoted in the papers, and accordingly do not cover by any means an exhaustive bibliography of the subject of waste heat recovery. They could have been improved if the practice adopted by some authors of giving initials as well as names could have been applied throughout. Again no reference is made to the discussions which followed the reading of the papers, and unfortunately references are not given in the volume to enable the interested reader to refer readily to them unless he has available the bound copies of the *Journal* for the particular years in which they appeared. These are, however, quite minor points for discussions of papers are not always the carefully reasoned meaty disquisitions they might be. On the major issues the volume comprises a useful handbook to both the experienced engineer or technologist and the earnest student.

The responsibility for the publication as a whole has been in the hands of a sub-committee of the Publications Committee of the Institute of Fuel under the Chairmanship of Mr. G. N. Critchley.

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Data Sheet 3

SPECIFICATION Nos. TENSILE STRENGTHS AND IZOD VALUES
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En. No.	Tensile Strength (Min) Tons/Sq. in.	Izod Impact (Min) Ft. lb.	Ruling Section Inches
34	45	40	Test Bar 1⅛" dia.
35	55	25	do. do.
325	55	35	do. do.
39B	85	25	Test Piece Size
320	85	25	do. do. do.

FOR NITRIDING

En. No.	Tensile Strength (Min) Tons/Sq. in.	Izod Impact (Min) Ft. lb.	Ruling Section Inches
40A **40B**	45	40	6"
	50	40	6"
	55	40	6"
	60	35	4"
40C	Higher Tensile*		
41	35	45	Izod Values applicable up to 2½"
	45	40	
	55	35	

*Mechanical properties as agreed between purchaser and manufacturer.

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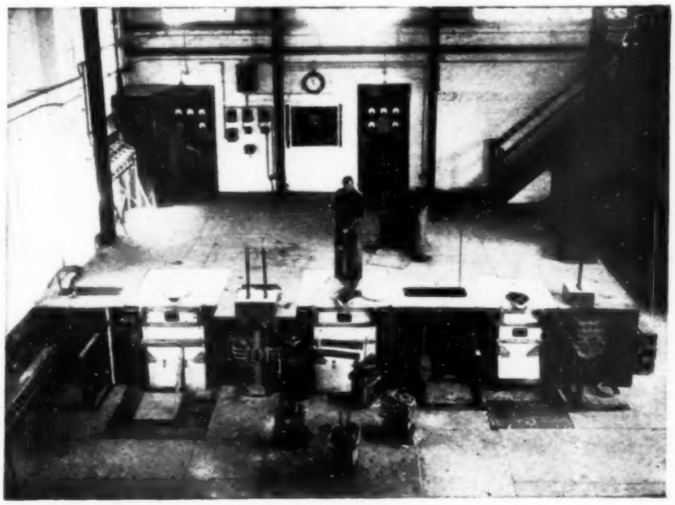

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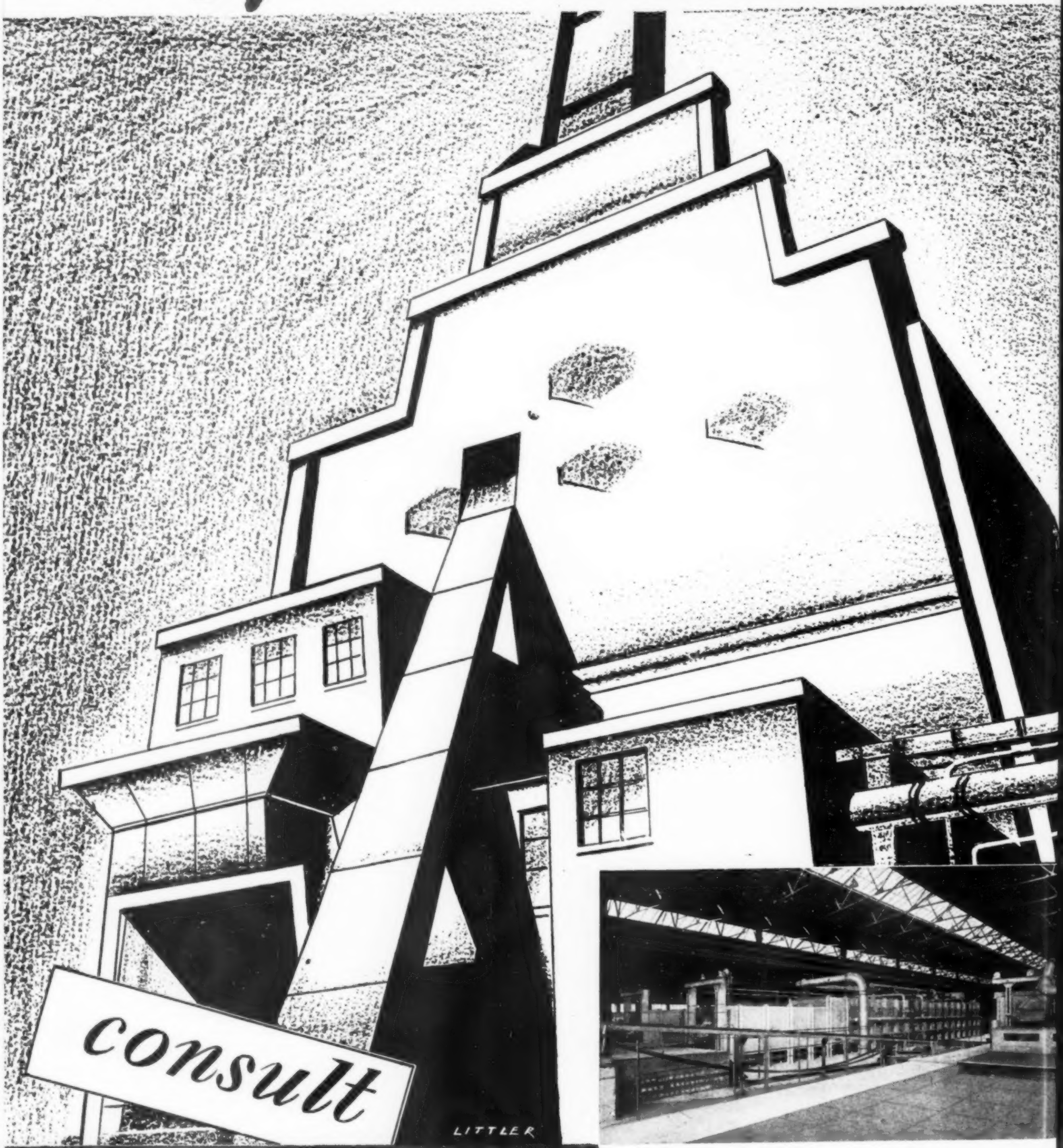

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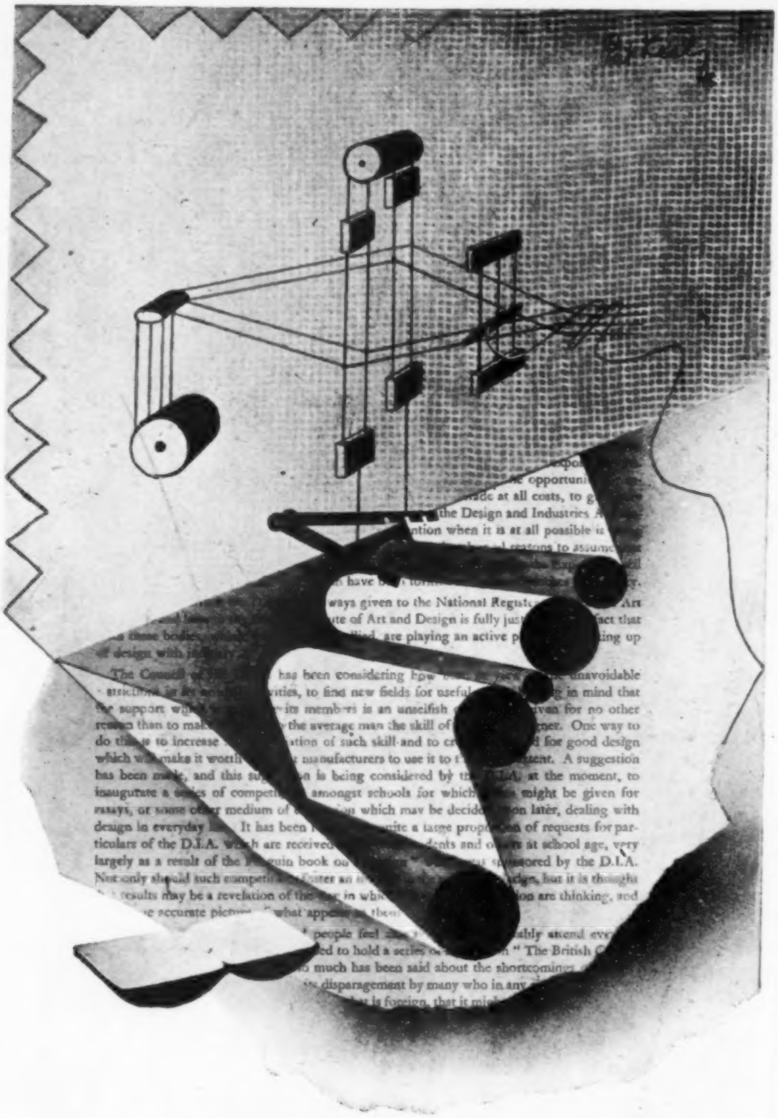

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The British Iron and Steel Industry

Success of an Experimental System of Public Control

The demand for steel since the end of the war has been abnormally high, and accumulated requirements could not be immediately satisfied. The position is rapidly improving, however, many of the worst shortages have already been overcome and it may not be long before the control of supplies can be substantially reduced. It is the production record of the last two years, which has improved beyond expectations, that justifies the claim that the arrangements under which the industry is now working have been an outstanding success. While the progress achieved is due largely to the combined activities of all concerned, the rapid progress of the development plan has contributed in no small measure and it is this aspect of production progress which is discussed here.

IN the early stages of the war it was decided by the Government that none of the country's resources should be diverted to the expansion of steelmaking capacity ; indeed, it proved impossible even to undertake the normal amount of repair and maintenance work, with the result that a certain loss in capital assets was inevitable. The effect of this was appreciated and before the war was over a special Committee was set up by the industry to survey the field and formulate post-war plans for reorganisation. Thus the industry was able to make a quick response to the Government invitation in May, 1945, to submit, within six months, a five year plan embodying the major improvements and new construction needed to overtake the war time arrears and to put the industry on a fully efficient basis. The British Iron and Steel Federation duly submitted to the new Government, which had taken office, a plan which was subsequently published as a White Paper.

This plan, which was approved generally by the Government, aimed at expanding the capacity of the steel industry from 14·1 to 16 million tons or at an increasing production rate from the 12·75 million tons level in 1946 to about 15 to 15·5 million tons on completion of the plan. The exact figure of future home production was likely to depend on the extent of imports of raw materials. It was intended to start all the schemes within the five years 1946/50 but, in view of the length of time required to complete some of the major schemes, the plan was unlikely to be completed to give full results before 1953. Total building of steel-making capacity under the plan was approximately six million tons, of which four million tons would be associated with the replacement of existing plant and two million tons for expansion.

Originally the plan was drawn up in such a way as to provide a considerable element of flexibility in case bigger outputs should be required. In consequence it has been possible to ensure that capacity will be available to meet the expected increase in requirements. The main problem, however, is not so much how to secure the necessary steel capacity as to be satisfied that there will be sufficient raw materials to make use of it. Broadly, the readjustment in the plan involves, not a substantial increase in new plant, but in using the six million tons of new capacity to enable four million tons of extra output to be secured and two million tons for replacement. Such a change in the balance between expansion and replacement had, indeed, become appropriate because the increase in the cost of new plant over the past few years has been so great that, in a number of branches of steel production, no economy would be shown at the present time in incurring major capital expenditure on new plants merely to replace existing capacity. Thus the economic life of some of the older plant is being extended beyond that originally anticipated.

Another objective of the plan designed to raise the industry's efficiency, was an arrangement for the concentration of production of certain finished steel items. Such centralisation of specific products in a limited number of works permits increased specialisation and more economical loading of plant, from which consumers and the national economy in general must eventually benefit. There are, of course, many schemes in the plan for individual plants but they are carefully integrated to form a logical structure, thus indicating that the Committee was concerned with the development of the industry as a whole.

While the cost of new plant has been advancing by about 12% per annum over the past three years and is now approximately 140% over 1938, there has been a narrowing of the gap between the high and low cost producers, particularly in the field of heavy plates and sectional material. In other branches of steel production, notably sheets and tinplate, and to a less marked extent in billets, the gap between the costs at new plant, including capital charges, and existing operating costs at the old plant is still big enough to warrant a substantial replacement policy as well as expansion. Indeed, in the course of working out the plan, schemes for expansion in both sheets and tinplate have increased as compared with three years ago. The large South Wales project, which will be among the largest of its kind in the world, is now being built to a capacity of 1·25 million tons instead of the million tons originally planned.

To secure a production possibility of 17·5 million tons of steel in 1953/54 it is planned to have available something like 18·5 million tons of capacity. A cautious view is taken of the production possibilities from a given capacity, although under conditions of pressure there is the probability that additional output would be secured if needed, as was the case with the capacity available during the war. On the present plans, which involve the importation of about half a million tons of steel, 17·5 million tons should be about the maximum requirement for home production on a full employment basis. This total is made up of 14 million tons for the home and export requirements of the steel using industries and 3·5 million tons of direct steel exports.

The plan links up with the outline given in the long-term United Kingdom programme recently submitted to the Organisation for European Economic Co-operation and published as a White Paper, in which figures given relate to a stage just before the completion of the plan, viz., to the period 1952/53. It is assumed that steel production in the United Kingdom at that time will be approximately 16·75 million tons with an import of about three-quarters of a million tons of ingots. This should be balanced by an export of about 2·75 million tons of steel if home demand is at the full level envisaged, as against an export of 3·5 million tons on completion of the full plan.

The marked affect of the home scrap drive last year in increasing the supply of scrap was sufficient to maintain the industry's expanding capacity even though supplies of imported scrap were, for a time disappointing. It is noteworthy that, during last year, an addition of 100,000 tons was made to scrap stocks, which during 1947 had run down to dangerously low levels. Difficulties of expanding both ore and coke supplies sufficiently readily will make it necessary for the industry to rely largely on high scrap deliveries for some time to come in order to secure a high level of steel output. Substantial quantities of scrap from Germany are unlikely to be available for more than a few years and, as imports will undoubtedly fall, it is planned in the more distant future to expand pig iron production to a level which will make scrap imports less important, although in calculating pig iron requirements under the plan no account was taken of this possibility.

The total requirements of pig iron for steelmaking are expected to increase to 10 million tons per annum and for iron foundries up to 2·75 million tons, giving a total requirement of 12·75 million tons. In making plans for blast furnace capacity and raw material requirements, a production of 13 million tons of pig iron and a quarter of a million tons of blast furnace ferro alloys has been assumed, giving a little surplus pig iron capacity.

Also contemplated in the future is an expansion of about 6 million tons of home ore and of nearly 4 million tons of imported ore. Schemes are already in progress for an expansion in home ore output and considerable progress has been made for the long-term development of increased ore imports from a number of overseas sources. But the raw material factor which seems most likely to limit output is the supply of coke. Although coke consumption per ton of iron produced has fallen from 22 cwts in 1946 to 20½ cwts in 1948, and is expected to fall still further to 19 cwts by 1953/55, there is still a need for a further three million tons of coke, which in turn involves an expansion of nearly five million tons of coking coal. The main expansion in coke oven capacity is taking place at the iron and steel works. Orders for this plant are nearly all in hand and work is proceeding, however, the time involved in building coke-ovens is so prolonged that difficulties in supply may be encountered, particularly in the period 1949/53 when additional blast furnace and steel capacity will be coming into operation, unless arrangements can be made in advance of coke-oven availability.

Since the beginning of 1948 steelmakers have been breaking all previous records. Following a production of nearly 12·75 million tons in 1947, an official target of 14 million tons was set for 1948; but the industry's performance of producing at the rate of over 15 million tons caused the Government to set a new objective of 14·5 million tons for the year. Even this revised estimate was beaten since the final figures for the whole year give a production of 14,877,000 tons. Encouraged by these achievements the Government set the industry to new target for this year—to produce between 15·25 and 15·5 million tons. During the first three months production has been at the rate of 15·85 million tons, but an all-time record in May, when output was at an annual rate of 16·4 million tons, indicates that forward planning and modernisation of equipment, and the good and willing relations with labour are facilitating achievements that were once thought to be impossible in this country.

It will be readily admitted that the success so far achieved in supplying steel demands is due in no small measure to the gradual progress of the development plan, but several other factors are making substantial contributions. Notable of these were the arrangements made in mid-1947 for the adoption of a continuous or extended working week in the steel melting shops, so that open-hearth furnaces need not be idle at week-ends. The advantage of this arrangement was made possible in many cases by the conversion of a number of the furnaces to oil-firing. It is well known that open-hearth furnaces fired by produced gas require to be shut down regularly for cleaning of the gas mains, a practice which is unnecessary when oil-fuel is used. It is also considered that scrap is reduced more quickly with oil-fuel and the process of steelmaking is correspondingly accelerated. These two factors, the adoption of the continuous working week and the conversion of about a quarter of the steelmaking capacity to oil-firing, provided the industry with a valuable addition to its capacity over and above that which it has obtained by the installation of new plant.

The success so far achieved has been assisted by the co-operation of the Government and other industries in reducing the raw material limitations, which interfered with the activities of the steel industry in 1947, in consequence it has been able to work nearer to the available plant capacity. The fact that the steel industry is one of the few to substantially improve on the production targets set indicates that private enterprise, functioning under a system of public control, the experimental application of which has proved so successful, can meet the demands for steel; there is certainly no evidence that a State steel monopoly would be better equipped to meet consumers requirements.

This plan of the British Iron and Steel Federation, accepted by the Government, and put into operation by the Iron and Steel Board, comprising an independent Chairman and six other members, representing trade unions, managements and a consumer of steel, together with a former Treasury official, provided the basis on which steel progress is being built. During the time the Board functioned it exercised wide powers of supervision over the industry in the national interest. It was not only concerned with programmes of development as represented by the plan, but looked after the provision of raw material requirements, exercised control and was responsible for general price policy.

The result of the relationship between the Government and the industry is of such a character that an effective combination of public control with private enterprise has been formed. This has proved so successful that the steel production rate during the first half of this year is on a basis of nearly 16 million tons. Even at this late hour the Government should reconsider various amendments to the Steel Bill in the national interest and in order that the public will have an opportunity to decide the political issue.

STEEL NATIONALISATION

By R. W. Allott, M.A.

Although we consider it unwise to experiment in the public ownership of such a complex industry until success has been achieved in other, less complicated, industries taken over by the Government, especially since, under public control, the industry is functioning so successfully, it is essential to know and consider the views of those who support the Bill now before the Houses of Parliament.

THE Iron and Steel Bill, having cut its way through the Report stage, and having been passed, on Third Reading, on May 9th in the House of Commons by a majority of 333–203, is now under consideration by the House of Lords, so that the present moment appears to be a suitable one for considering the possible implications of the nationalisation of the steel industry, which it involves.

The primary concern of the steel industry, as of this Journal, is to see that steel is produced by the most satisfactory means to meet the nation's demands, whilst the aim of the Bill is to make available steel in such quantities, of such types, qualities and sizes and at such prices as may seem to the Iron and Steel Corporation of Great Britain best calculated to further the public interest in all respects.

Both sides seem, therefore, to be *ad idem* on the object to be attained and it is in the methods by which, and the ends for which, this object is sought that the conflict arises. But this difference of aims and principles is fundamental, not amenable to logical argument nor to conviction by material factors, in whatever strength or number such material arguments may be put forward. The Socialist view is that the steel industry should be owned by the State, controlled by the State, and developed to serve the public interest and not any sectional private interest. The Conservative view is that the State may control the industry, as it has done for many years past, but that the running of the industry must be left in the hands of private enterprise.

This divergence of views colours the whole argument and the same set of facts is viewed in diametrically opposed ways by the two parties. Thus, the Conservatives say that the industry is too complex to be safely taken over and run by the State, whilst the Socialists say that it is because of its very complexity and its importance in the national economy that the steel industry can no longer be safely left in private hands but must be integrated into the industrial structure of planned national system. There is the additional Socialist argument that armaments, for which steel is the chief basic material, must be publicly controlled to avoid the scandal of arms supplies to potential future enemies, as has been the case since Sussex cannon armed the Spanish fleet in the days of the Armada.

Similarly, the arguments based on the present output records of the steel industry are differently interpreted. Steel production in Great Britain is now running at the rate of 16,000,000 tons a year, as compared with 13,250,000 tons in 1939. The private owners claim this as a justification of their control and handling of the industry, particularly in the last few years, whereas the Trade Unions claim that the increased output is due to their agreeing to continuous seven-day week working by their members. The truth is that it is by the combined efforts of management, technical staffs, and workmen, that these results have been achieved. Whatever may be the future of the industry, it will be this trilogy of brain, nerve and muscle which will work the machine, a fact which is being increasingly recognised in Labour circles.

But even in the motives for increased production in recent years, there is the same dichotomy. Owners have been working to prove that Nationalisation is not necessary in a well-conducted expanding industry, thus hoping to avert it by their efforts, whilst the workmen have been encouraged in their efforts by the promise of early nationalisation of the steel industry, fear on the one hand, hope on the other.

Turning to the history of the industry in recent years, it is claimed that strict Government control has prevented any abuse of public welfare and that a continuation along the same lines, with continuing private ownership, would be the best policy. This argument, of course, fails, because of the fundamental difference in outlook, as mentioned above. Also, it is argued that such control has been negative, preventing abuses, whereas a positive control to formulate and implement improvements is absolutely essential.

It is said that the steel industry is too big to be run as a single Corporation, but its output of 16,000,000 tons a year is to be compared with the output of 29,250,000 tons by the United States Steel Corporation in 1948, or that of 13,500,000 tons by Bethlehem Steel Corporation in that year. Obviously, this is affected by the size and number of plants involved in both cases. The years of war have prevented adequate scrapping and replacement of obsolete plant in Great Britain, so that by 1945 one-third of the plant was due for scrapping. The question is shall the financing of this re-equipment, some £180,000,000, be done by private means, with the cost entailed, or by Government finance.

So too for research work, particularly long-term research, the Government has already taken a lead in this field, and it seems very probable that it is only by a national system of research, financed by public grants, that future developments on the scale now required will be possible of achievement. Communication and inter-availability of results of such research will be imperative to maintain our place in the world of scientific progress, with the minimum waste of time and money in overlapping experiments.

As regards the effects of nationalisation, both sides are equally emphatic and equally opposed. The primary purpose is, of course, to give control to the State, and this will be applied at the top, so that there will probably be very little change in the running of the industry in its lower reaches, granted the goodwill of present staffs and workpeople, in the national service. The details of the Iron and Steel Bill are well known, so that it is not necessary to define the branches and the proportions of the industry which will be directly taken over, or those which will be controlled by licences.

No differentiation has been made in the Bill between ordinary steels and special steels, although these two branches of the industry have quite separate problems and serve very different purposes. The 1,000,000 tons of special steel produced in Sheffield per annum is worth more in the industrial economy of the country than the other 14,000,000 tons of mild-carbon steels, since it is those specials steels, machined and elaborated by engineers and craftsmen, which form the most valuable portion of our export and our home trades. Machinery, vehicles, electrical plant, etc., are our most valuable exports, and it is the supply of special steels for their manufacture which must be most carefully controlled and ensured, if the industrial future of the country is to be safeguarded. The lines of policy on this matter, as on the need for retaining raw steel in the country for further work to be put on to it before export, can only be decided, and carried out by a Government body, free from the conflicting claims of numberless private interests. The Bill, as at present drawn, does not cover the position of special steel manufacture nor of that still more special series of steels, the tool steels.

As a result of the nationalisation of the mines, of transport (railways, road transport, canals), of electricity and gas, the largest customers of the steel trade, in addition to the Services, are now under Government control, so that it is essential that their supplies of a basic material, such as steel should be safeguarded and ensured by some public control. It is owing to the standard specifications of such bodies and Services in the past that the quality of British steel has been maintained and improved to its high level, and this would be maintained, a fortiori, in the future, since all these bodies are under Government ownership, and the element of private profit, in its reaction to specification, no longer comes into play.

The trading between nationalised bodies will be on a contra-account basis, without profit being necessarily made, so that an equation of services mutually rendered will lead to a simplification of accounts and a decrease in the monetary turn-over requirements. Selling costs should be thus reduced, by elimination of the present duplication, and other economies effected.

It is not proposed to discuss the terms of the Bill—there has surely been ample discussion in the technical and daily Press—but it may be remarked that the method of obtaining control of the various firms by purchase of their shares is considered to be the normal method by which private interests obtain such control, so that the Government is following a normal procedure, after giving some measure of warning of its intention so to do.

Nationalisation of steel has been advocated by the Iron and Steel Confederation since 1931, adopted by the T.U.C. in 1934, and endorsed by its Congresses in subsequent years, so that, for its members, this is the culmination of its hopes over many years. Memories of unemployment in the years between 1929 and 1938 are still vivid, as 28% of steel workers were then unemployed and 23% of blast furnace workers. It must, therefore, be recognised that nationalisation is a matter of faith and hope for the workers in the industry, not a mere political shibboleth. Relations between owners and men in the steel industry have been very good for many many years, and there has grown up a mutual respect, a tolerance and a readiness to see both sides of the picture, which it is hoped will continue in the future conduct of the industry under national ownership. The mistakes of previous nationalisations must be avoided (e.g., over-centralisation), and, whatever issues from the present deliberations, endorsed or rejected by the final Court of Appeal, the electorate, all the workers in the steel industry, management, technical and professional staffs, and workmen, must combine for the national well-being.

It has been said, by the President of the Association of Technical Institutes, that "The feeling of those actually engaged in the steel industry is that it does not matter so much who *owns* the industry but who *manages* it and *runs it*," a feeling which the readers of this journal may very well endorse.

Recruiting and Training for the Iron and Steel Industry

THE British Iron and Steel Federation have recently circulated to all member firms a sample training scheme to be applied, according to local circumstances, in individual groups of firms which are willing to take apprentices in the iron and steel industry.

The scheme, which has been approved by the various trades unions concerned, broadly covers four categories of employees, namely: junior operatives, craft apprentices, clerks, and technical apprentices. Recommendations are made in it about introduction to employment, general education, practical training, appointment of training officers together with liaison and co-operation with local Education Authorities and the Ministry of Labour's Youth Employment Service. Provision has been made for the appointment of local committees, and considerable progress has been made with their formation.

Part of the scheme, that dealing with apprentice technicians and craftsmen, has made considerable progress in a large works in Scotland. The general outline is a 3-weeks course of lectures, during which, entrants are shown instructional films and taken round the Company's various works. At the end of the class the boys are asked to write an essay giving their reactions to the course. From this 3-weeks course the boys are transferred to their various jobs. During training they attend technical classes, one day a week, at a technical college, fees, wages, and travelling expenses being paid by the firm; they also attend lectures at the works' school.

A regular curriculum has been prepared to cover the phase training in all trades dovetailing machine and departmental transfers to ensure an all-round training for the apprentice in as wide a field as possible. Progress and transfer records are carefully checked to eliminate too long a period on a particular job and effect a smooth working arrangement. Progress, efficiency and a sense of duty offer incentive at each stage and the transfer system keeps the lad's mind fresh and happy on the job.

The same firm have an excellent Sandwich Scheme administered by a panel of Senior Executives, which annually considers recommendation of apprentices by Works Managers for entry to a 4-years course at a University or Technical College on the basis of 6 months at College and 6 months on specialised defined training. The scheme is open to all apprentices who can thus climb to the higher posts in the industry.

Electric Iron-ore Smelting

By Dr. Mohammed A. Kassem

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In countries blessed with a plentiful supply of cheap electricity, the electric iron-ore smelting process is finding increasing application. The low-stack furnace, which is adopted generally for the process, does not call for such control of the physical properties of the constituents of the charge as does the blast furnace. In addition the gaseous products of the electric furnace are of high calorific value and for full economy of working it is essential to plan their utilisation to the best advantage.

THE electric iron-ore smelting process has recently attracted considerable attention and its application is proceeding steadily. It is of particular interest to those countries which are poor in coal deposits but in which there is abundant potential water power for the generation of the necessary electrical energy. Accordingly large electric iron-ore smelting furnaces, up to 15,000 kva. capacity, have been erected in certain countries, with the sole object of avoiding the import of the otherwise necessary prime quality foreign coke, which is not only expensive but, under certain conditions, extremely difficult to obtain. Due to the fact that a considerable amount of coke, roughly equal to the amount of iron produced, is necessary for the normal blast-furnace process, it is not surprising that some countries prefer to export their ores rather than smelt them themselves.

It will be realised that the coke consumed in the blast furnace, in addition to supplying the carbon needed for the reduction operation itself, together with that necessary for alloying, must also provide the total heat requirements of the various processes occurring during smelting and the heat losses of the plant.

The replacement of the quantity of coke necessary for these heating requirements, which may be termed "heating coke," by other heat producers is an obvious possibility. To this end one may use other fuels, or even electrical energy. The only condition obtaining is that sufficient heat should be produced at suitable temperatures, and, of course, that no serious qualitative, quantitative or, more especially, economic factors should affect the production.

Early Furnaces

The logical step from these considerations is that the replacement of "heating coke" by electrical energy should be attempted in those countries which are poor in coal but rich in water power. The electric iron-ore smelting furnace was thus developed in Scandinavia. In Sweden the simple introduction of electrodes into the blast furnace resulted in the development of the so-called "Grönwall," "Lindblast" or "Stalhane" furnace of the Elektrometall Company. It was soon found, however, that the reduced amount of gas, due to the smaller amount of coke used and the absence of the "ballast" nitrogen of the air blast, gave up its sensible heat at a low height and rendered the stack superfluous. The characteristic form of the bosh was also found to be unsuitable and these two factors, the uselessness of the stack on the one hand, and the unsuitability of the otherwise common form of the bosh on the other, opened the way for the stackless or low-stack electric furnace in the iron industry.

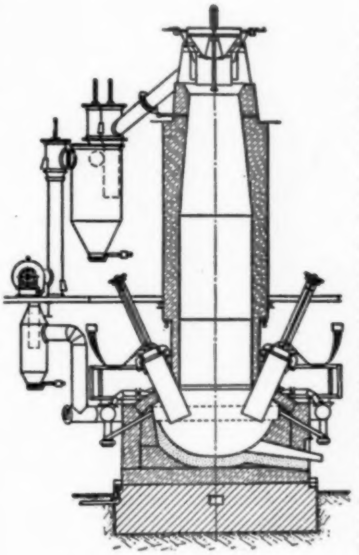

Fig. 1.—Grönwall furnace

The "Grönwall Ofen" working in Porfos (Fig. 1) possesses a stack of 3·25 m. diameter and a total height of 13·25 m. The smelting zone is 5·1 m. in diameter and 2·24 m. high and six electrodes, diametrically connected in pairs and fed from a three-phase generator, supply the current to this zone. To reduce the dangerous effect of the high arc temperature on the vault the latter is cooled by blowing pre-cooled furnace gases on the exposed side. This gas circulation may also serve an additional purpose in effecting a partial reduction of the charge in the stack.

The Low Stack Furnace

A more successful and modern low stack electric iron smelting furnace, the Tysland-Hole-, Tysland- or Spigerverk furnace, was developed in 1922 by G. Tysland in Norway. Shortly afterwards, in 1925, the first three-phase 6,000 kva. furnace was constructed by the Christiania Spigerverk. Since then it has been considerably improved by J. Hole, particularly with regard to the location of the electrodes (Fig. 2). This type of furnace can be considered as the most suitable for electric iron-ore smelting to-day and, as I was fortunate enough to assist in the erection of a 7,500 kva. furnace of this type, and later to manage it, I should like to describe it briefly.

It consists chiefly, as will be seen from Fig. 3, of a low, broad hearth equipped with a vault and lined internally with clay earth, magnesite and carbon bricks. This lining is further covered, on the bottom and almost up to mid-height, with a special carbon-stamp mass. Three vertically movable Söderberg electrodes dip through the vault to the inside of the hearth. Each electrode is suspended by two steel strips, on the Wisdom system, the free ends of the rolled strip being welded

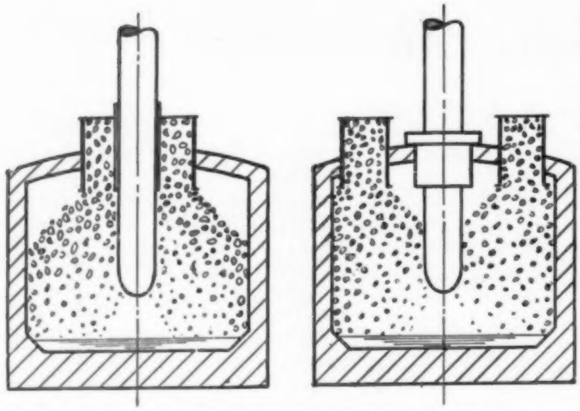

Fig. 2.—Left: Section through Tysland furnace; and Right: Section through Tysland-Hole furnace, incorporating improvements in electrode location.

axially to the electrode casings after each has been passed through a pair of brake jaws. The casing consists of an internally ribbed welded sheet steel cylinder which is filled with electrode paste, made by mixing anthracite with a pitch-tar binder. The electrodes are self-baking and can be increased in length, as they burn away, by welding on a further casing at the top end and filling with paste. In this way operation is continuous. Movement of the electrodes may be effected hydraulically using either hand- or automatic control. As the transformed secondary current to the furnace is high, being about 21,700 amps./phase (i.e., 37,500 amps./line) and the transmission losses are proportional to the square of the current, a low-power factor will be the normal result. By arranging the current to flow in opposite directions in adjacent bus-bars, as indicated in Fig. 6, the impedance is reduced to a minimum with a resulting improved power factor.

The charge passes to the furnace through specially constructed silos, the molten iron and slag being withdrawn separately through special tap-holes.

The gases leave the furnace just below the vault and, by means of a special water valve (Fig. 7), are directed either to the chimney or to special equipment for purification (Fig. 8) prior to utilisation. As the gases consist chiefly of carbon monoxide, which is very poisonous and, with air, forms an explosive mixture over the range 16·6%–74·8%, certain precautions had to be taken to ensure the safety of the plant and personnel. The gas pressure within the furnace was automatically regulated (Fig. 9) to a pre-determined value which allowed the gases to be withdrawn from the furnace, instead of escaping from the charging holes and, at the same time, prevented air entering the furnace to form an explosive mixture therein. It is of interest to mention that, during the intense continuous operation of two war years, there was not one single accident from this source. It may be mentioned, in passing, that the indications of the control instruments in themselves are not sufficient for control, but the experience of the engineer in charge is of vital importance.

Advantages of Electric Smelting

The relative advantages of this electric method of pig-iron production will be apparent from the following considerations :—

The coke consumption of a modern blast furnace is about 1 ton/ton of pig iron. Depending on the nature of the charge and of the iron produced, and also upon the size and capacity of the furnace itself, this amount may vary within ± 25%. The coke consumpton of the electric furnace is considerably less, due to the replacement of the "heating coke" by electrical energy. The carbon required for reduction and alloying cannot be so replaced, of course, and must be charged in some form or other.

In the 7,500 kva. furnace the coke consumption was reduced to 350 kg./ton of pig iron, with an energy consumption of 3,000 kwh./ton of pig iron. Such figures again depend on the nature of the charge and the iron produced, and on the size and capacity of the furnace. In addition to this saving of some two-thirds of the coke consumption of the blast furnace, there is a further qualitative economy in that prime quality coke is not necessary. Waste coke, non-coking coal and even lignite are quite suitable for the purpose. In the aforementioned 7,500 kva. Swiss furnace, the use of a local anthracite containing about 60% ash has been found successful. Such anthracite is clearly more like stone than fuel. It does not and cannot burn and until it found its way to the electric smelting furnace it was quite useless. Now it is very useful and serves as a stone in the building of Swiss economic and industrial independence.

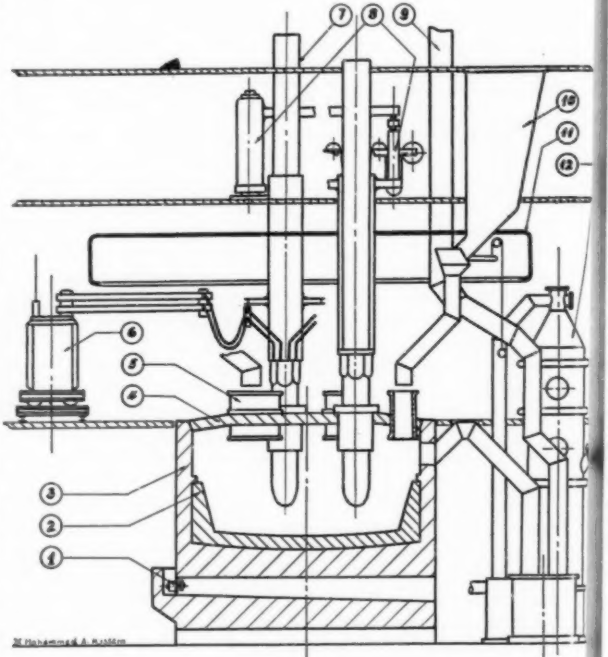

Fig. 3.—Tysland-Hole furnace.

1. Ventilators for cooling bottom of furnace.
2. Stamping mass.
3. Furnace wall.
4. Vault.
5. Charging chutes.
6. Transformer.
7. Case of electrodes.
8. Hanging equipment of electrodes.
9. Chimney.
10. Charging silos.
11. Gases cap.
12. Washing tower.

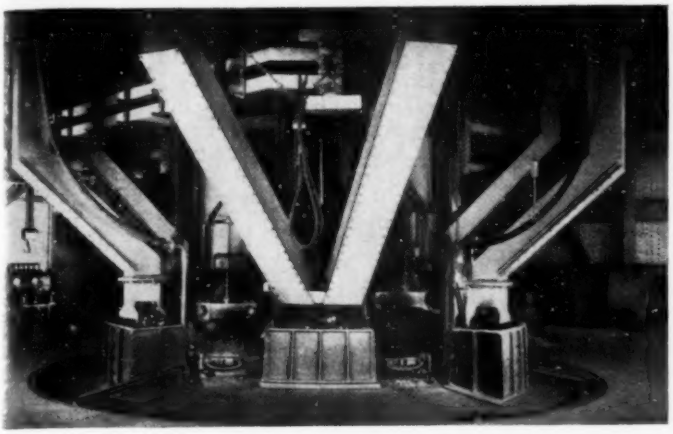

Fig. 4.—Vault of Tysland-Hole furnace. Two of the Söderberg electrodes and some of the charging silos are visible.

Furthermore, with the electric furnace, a good deal of the reduction carbon is recovered in a much-improved form in the exhaust gas as may be clear from the following considerations. About 800 m.^{3} of gas are produced per ton of pig iron, in the electric furnace, as compared with some 4,000 m.^{3} per ton in the blast furnace. In electric smelting, there is practically no gas consumption by the plant itself, whereas in the blast-furnace process some 25% is used for preheating the blast and a further 30% for generating it. There is thus only 45% or 1,800 m.^{3} left for external use. This is still more than double the amount from the electric furnace but its calorific value is only about one-third of that of electric-furnace gas, due to the useless ballast of nitrogen in the blast-furnace gas. Consequently, whilst the calorific value of the electric-furnace gas has been found to be about 2,400 k.cal./m.^{3}, that of blast-furnace gas is only about 800 k.cal./m.^{3}. Thus, considering the total quantity of heat available in the two processes, the electric furnace produces $800 \times 2{,}400 = 1{\cdot}92 \times 10^6$ k.cal./ton of iron as compared with $1{,}800 \times 800 = 1{\cdot}44 \times 10^6$ k.cal./ton of iron in the blast furnace. This advantage of about 0·5 million k.cal./ton of iron represents a recovery of about 60 kg. of the reduction coke per ton of iron produced. It is evident that, in the blast furnace, prime quality coke is converted into heat energy—the worst of all transformations in any case—and a gas of low thermal value is produced, whereas, in the electric furnace, the poor quality fuel is not converted directly to heat energy and a valuable, rather pure gas of good heat content results. This gas with its 2,400 k.cal./m.^{3} calorific value can then serve as a good fuel, as a reducing agent for further iron extraction, as in a suitably modified " Wiberg " process, or as a valuable raw material for various chemical industries, as in the production of synthetic petrol by the Fischer-Tropsch process.

In addition to the above arguments there are other points which may be taken into consideration, to justify the probable high cost of electrical energy; e.g., the high quality of the iron produced, particularly as regards sulphur content. The cost of electrodes is also more than counterbalanced by the elimination of the numerous auxiliaries, such as Cowper stoves, blowers, etc., required for blast-furnace operation.

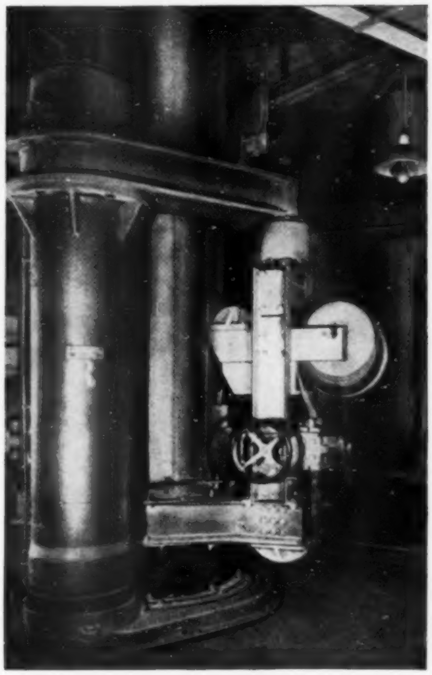

Fig. 5.—Wisdom system of electrode suspension.

Accordingly, electric ore smelting may be practised, not only in coke-poor and water-rich countries but also in coke- and water-rich ones, when the coke can be reserved for use as raw material in the chemical industry, particularly for synthetic petrol production by the catalytic pressure hydration process named after Berguis.

Costs

Naturally the cost of electrical energy should not exceed a certain limit for the electric smelting process to be economically successful. This limit may be roughly found as follows: Theoretically, 1 kg. of coke corresponds to 8 kwh. (assuming a calorific value of about 7,000 k.cal./kg. for coke) as the thermal efficiency of coke and electrical energy are nearly the same for heating purposes. Consequently, economic parity, as between coke and electrical energy, is attained when 1 kg. of coke costs eight times as much as one kilowatt-hour of electrical energy. Where there is a balance of an electrical peak load available, however, the conditions are better for electric smelting and parity may be attained at a cost ratio of 6 : 1.

Whilst modern furnaces of the Tysland-Hole type are in successful operation, it should be pointed out that a more highly qualified staff is required than in the case of the blast furnace. The charge must not only be calculated to give the desired quality of iron, but it must also suit the working conditions of the furnace. In other words, in the construction of the furnace several factors have to be taken into consideration so that its working characteristics will suit the proposed charge. Otherwise, the furnace will not be operating under its most economical conditions, or the desired quality of iron will not be produced. A new theory of the technical manag-

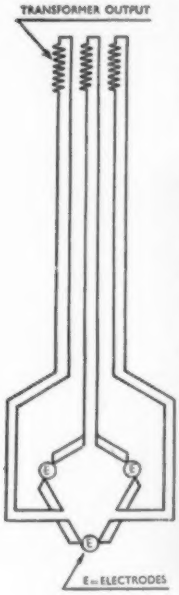

Fig. 6. Switching Scheme.

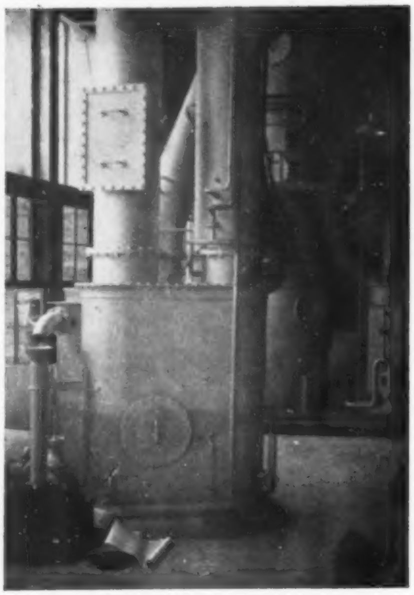

Fig. 7.—Special two-way water valve for directing the gases.

ing and working control of such furnaces, together with other practical problems, was published by the author in 1945.*

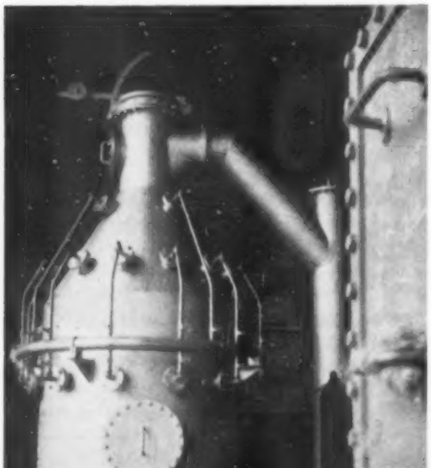

Fig. 8.—Upper part of the gas-washing tower of the purification equipment.

In the aforementioned 7,500 kva. furnace, although several kinds of ore were treated, some of which were inferior, containing only 30% iron, the physical and chemical conditions of the charge could be harmonised to suit the working limitations of the furnace so that the desired quality of iron was produced with a power factor of about 0·9. Moreover, certain types of cast iron were produced directly from the heterogeneous and waste raw materials. That the charge consisted of about ten iron-bearing constituents was due to the fact that as Switzerland has practically no iron ores, all that was found to contain some iron found its way to smelting. The composition of each type also fluctuated considerably, giving additional troubles.

Gas Utilisation in Cement Manufacture

The gas problem is very important. As a valuable source of energy its use should be considered from the start ; it should not be lost by simply burning in air. Due to its poisonous and explosive nature it should not be liberated to atmosphere and if it cannot be utilised it should be burnt. If the chemical utilisation of the gases is not possible, then the thermal use should be ensured. In many cases they can replace coal, which has to be imported, for heating annealing furnaces and the like.

Where the raw materials for cement manufacture are available, a cement factory adjacent to the smelting plant might form a useful combination. The fact that the iron smelting slag can be used in cement manufacture is a further advantage. Slag and cement are both calcium-aluminium silicates with the cement the richer in CaO. If the requisite CaO is added to the granulated and milled slag, then the product is the so-called " slag cement " which is not inferior if it is kept moist whilst it is hardening.

If the slag sand be burnt to clinker with the requisite lime, the product can be milled to the so-called " iron Portland cement " which is practically the same as Portland cement.

Alternatively, the simple addition of the powdered slag sand to Portland cement helps to increase the cement production and, if the addition is kept within certain limits the mechanical properties of the cement

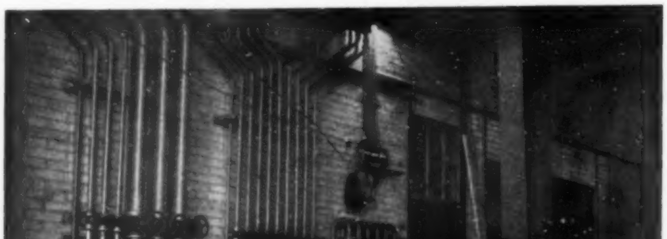

Fig. 9.—Automatic gas-pressure regulator and cooling- water control centre.

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* *Schweizer Archiv*, No. 3, March, 1945, p. 87.

are unaffected, or at least not seriously affected. Moreover the Portland cement clinker usually contains some uncombined lime which tends to cause blooming of the cement. Consequently, an addition of slag, which is deficient in lime as compared with cement, would help to neutralise the excess lime and prevent blooming. Swiss tests showed that Portland cement satisfied Swiss standards for mechanical properties even after an addition of 15% slag. Such slag additions have been practised for some time iin certain iron-producing countries such as France and Germany.

When, by the electric smelting of 1 ton of pig iron, some 700 kg. slag are produced, in addition to 800 $m.^3$ of gas of 2,400 $k.cal./m.^3$, the utilisation of these by-products in an annexed Portland cement works yields some interesting figures.

If the high Swiss standards are followed and no more than 15% slag is added, the 700 kg. slag should be mixed with 4·6 tons of Portland cement clinker. As the production of cement clinker in a rotary kiln consumes some 1,200 k.cal./kg., then the available heat from the electric iron-furnace gas would produce $\frac{800 \times 2{,}400}{1{,}200 \times 1{,}000} = 1{\cdot}6$ tons of clinker. Accordingly, of $4{\cdot}6 + 0{\cdot}7 = 5{\cdot}3$ tons of Portland cement, $1{\cdot}6 + 0{\cdot}7 = 2{\cdot}3$ tons are produced without fuel charges. This corresponds to a saving of $2{\cdot}3 \times 1{,}000 \times 1{,}200 = 2{\cdot}76 \times 10^6$ k.cal., which is equivalent to the heating value of about 400 kg. long-flame coal.

All these calculations are based on the production of 1 ton of pig iron in the electric furnace. As this requires about 350 kg. of coke it will be evident that this latter amount is more than counterbalanced by the saving of 400 kg. in cement production, so that it may be said that the iron is produced without coal.

From these considerations, the necessity of planning, from the start, the industrial use of the electric furnace gas will be appreciated. As further confirmation, it may be stated that the gas from the 7,500 kva. furnace, amounting to 35,000 $m.^3$/day would cover the requirement of a town of 100,000 inhabitants using gas as the principal household fuel.

Naturally it is more rational for an iron-ore smelting plant to utilise such gases in the smelting operation itself, thus increasing the output and decreasing production costs. Having both thermal and reducing properties, the gases may be used to contribute to the heat requirements or for the additional ore reduction depending on the local conditions. Where electrical energy is scarce the thermal utilisation of the gases is advisable; on the other hand, where coal is scarce they may be more usefully employed in effecting additional reduction by such "direct" processes as a suitably modified Wiberg process.

Use of Gas for Direct Reduction

In the latter process the reduction is carried out by carbon monoxide in a stack-like furnace. As the reducing gas becomes diluted with carbon dioxide it will eventually lose its effect as a reducing agent. Such a stage will be reached when the reaction $FeO + Co \rightleftharpoons Fe + Co_2$ approaches equilibrium at the local conditions of temperature obtaining. Accordingly, the gas is partially drawn off when its temperature reaches 950° C. (i.e., at some intermediate stage before the top of the stack is reached), regenerated in special carburators and preheated to about 1,000° C. before recirculation. The rest of the gas is allowed to do further reduction until the reaction $Fe_3O_4 + CO \rightleftharpoons 3\ FeO + CO_2$ approaches equilibrium, when the gas is ignited with air and used for preheating the ore. A modification of the process, for use with an electric-smelting plant, would consist in the elimination of the regeneration of the reducing gases as they are continuously available from the smelting furnace.

From the foregoing, it is evident that such a procedure would involve the erection of a subsidiary plant to work in conjunction with the main one. Moreover, only pure ores—i.e., those consisting of iron oxide only, or those from which the impurities can be easily and economically separated, are suitable for the successful working of such "direct" processes, working at a temperature below the melting point of iron. Such pure iron ores are scarce and the separation of the impurities in the solid state, before or after reduction, has very limited practical and economic application. In addition a powdered ore and final product is conditional for ease of reduction and purification in the solid state. It will be seen, therefore, that direct reduction at low temperatures is only rational where pure ores are available in powder form. The purification by melting and slagging needs additional heat, and in this case it is more reasonable to carry out the reduction from the beginning in the fused state. All the so-called "direct" processes for the reduction of iron ores are beset with such difficulties and, with but few exceptions, governed by favourable local conditions, it may be said that such processes as a whole are not yet developed to the stage when they can be considered as competitors of the present smelting methods. In consequence, the thermal utilisation of the electric furnaces gases may be preferred. They may be used to cover part of the heat requirements of the smelting process and thus reduce the required transformation of electrical energy into heat. Heat is always the last form of energy in any transformation, and while it is easy to attain 100% efficiency the reverse transformation is only possible with relatively poor efficiencies. Accordingly it must be judged as poor technical economy to transform, intentionally, other forms of energy into heat.

As already stated, the gas generated per ton of pig iron is equivalent to some $1{\cdot}9 \times 10^6$ k.cal. The normal heat requirements for the production of 1 ton of pig iron, $2{\cdot}5 \times 10^6$ k.cal. are supplied by electrical energy in modern smelting, but if the gases were used thermally in the smelting operation, only $0{\cdot}6 \times 10^6$ k.cals. would require to be produced electrically. In other words 700 kwh. would be sufficient for the production of 1 ton of pig iron instead of the present 3,000 kwh. This alone is a considerable economic factor, but when considered with the fact that extremely poisonous gases would be destroyed in the furnace itself, or even in its approaches, the value of such a method is considerably enhanced.

It is hoped that sufficient has been said to convey some idea of the technical and economic aspects of present and future developments of electric iron-ore smelting, an industry in comparative infancy.

Two of the blast furnaces at the South Iron Works of the Appleby-Frodingham Company, produced 7,200 tons of iron during the week ending June 18th, working on a normal burden. This surpassed by 80 tons the previous best week's output, recorded in August, 1940.

The Bessemer Process

Some Aspects Arising from a Study of Practice

An informative Report by a Sub-Committee, appointed by the British Iron and Steel Research Association, which has been investigating the possibilities of increased uses for Bessemer steel, has become available. It is suggested that developments in practice abroad merit investigation in this country, and that, in order to ascertain the full extent of the uses to which Bessemer steel may be put, the British Iron and Steel Research Association should conduct an investigation in which ingots made by the Bessemer process would be manufactured into products not usually made in Bessemer steel.*

An acid Bessemer converter in operation at the works of the Workington Iron and Steel Co. Limited.

THE development of the Bessemer Process had a revolutionary effect on the iron and steel industry not only in Great Britain, but in all steelmaking countries and the process was adopted wherever steel for constructional purposes was produced. Its introduction resulted in the production of what amounted to a new metal—mild steel—which could be substituted for malleable iron at less than a third of the cost of previous metals, it is therefore not surprising that, within a few years of its discovery, the process was largely responsible for rapid development in the steel industry.

Important however, as the process proved to be, from economic and technical points of view, it had serious limitations in practice, due to the lack of uniformity in the quality of steel produced. But the process proved so successful that early experiments of Siemens in this country were abandoned for a time, his open hearth process, however, was subsequently further developed by the Martins and, due to the greater control of the product in Siemens furnaces, the open hearth process gradually gained favour and, for some time was almost wholly the method employed for steelmaking in this country. There was an almost continual decline in the amount of steel made by the Bessemer process from 1910. Apart from a small amount in 1929 no steel was produced in this country by the basic Bessemer process from 1926 to 1934, although Continental production continued at a fairly high level.

Since 1934, however, largely as a result of investigation of the economic aspects of the process for making steels for particular products, two plants for the production of basic Bessemer steel have been put into operation, one by Messrs. Stewarts and Lloyds Ltd., at Corby, and the other by Messrs. Richard Thomas and Baldwins Ltd., at Ebbw Vale, and the present annual production of basic Bessemer steel in this country amounts to about 720,000 tons.

In an effort to arrive at conclusions regarding the possibilities of using the Bessemer process in this country to a greater extent, investigations have been in progress for some years by a Sub-Committee which has submitted an impartial Report on the process. This Report is extensive; it has been divided into three main parts, viz.: British Bessemer practice; foreign Bessemer practice; and future Bessemer practice; details of particular plants, etc., are given in the form of appendices. It is noteworthy that, in order to obtain an impartial Report, the Sub-Committee was originally composed of open-hearth steelmakers who nominated the Bessemer steelmakers subsequently serving.

The Report is concerned only with processes that are working, that have worked, and possible combinations of these. In addition it enumerates as far as possible the uses to which Bessemer steel is being and has been put, and indicates possible lines of research which might lead to the development of new applications for Bessemer steel. As mentioned previously, this Report is extensive and in the following review an effort has been made to present some salient features.

British Bessemer Practice

The Basic Process.—The first experiments on the manufacture of steel by this process were made by Sidney Gilchrist Thomas in 1876 in Wales. By 1879, the process was being worked on a commercial scale in Wales and at the works of Bolckow, Vaughan and Co., Middlesbrough. After 1910, there was almost a continual decline in the amount of steel made by this process and during the period 1926–1934 production ceased entirely. At present the two works in Britain making ingots by the basic Bessemer process, at Corby and Ebbw Vale, have been built within the last fifteen years. The Corby plant has five vessel stands and the Ebbw Vale three, and both plants blow only one vessel at a time. The vessels are of 25 tons capacity. The average air volume is 20,000 cu./ft. min., the pressure varying from 20 to 27 lb./sq. in., according to the ejects blown from the vessel; the duration of the blow is usually 15–20 mins. Neither plant uses spectroscope nor photo-cell to get the end point, this being accomplished by visual observation of the flame and confirmed by inspection of a spoon sample drawn from the converter; if doubt exists, further confirmation can be obtained by observation of a broken sample. Constancy of the phosphorus content confirmed the efficacy of this method of assessing the end point. Neither plant seems to have done any systematic work on oxygen content of the steel on completion of the blow nor on the relation between slag and steel compositions; the necessity has not arisen. The ingots which the Sub-Committee saw being cast, and the answers which the members received to their questions on the subject showed a constancy of rimming behaviour that was remarkable. At Ebbw Vale no aluminium is added in the ladle and about 3½ oz. per ton of steel is added to the moulds, while at Corby an addition of about 6 oz. per ton is made to the ladle and up to 1 oz. per ton is added to the moulds. The control of the oxide content by the photo-cell or other means, and the question of the connection between the slag composition and that of the steel quality may yet arise.

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*This will shortly be published as a Special Report by the Iron and Steel Institute.

The control of temperature during the process has an important bearing on the nitrogen content of the steel. At the Ebbw Vale works the production of low-nitrogen steel is achieved by strictly regulating the final temperature to the range 1,580°–1,600° C., the temperature of each blow being measured. Of course if the temperature falls outside these limits nothing can be done to improve that particular blow, but the blower is able to do something about the next one. It will not be out of place here to indicate how the final temperature of the previous blow gives the key to the next blow. The blower uses iron from a mixture the composition and temperature of which are known, and a given weight of iron is used each time; a given lime weight is added to the vessel, which is at the same temperature as for the previous blow, a similar blowing practice is adopted and a constant scrap (or ore) addition is made. With the single variation of the scrap (or ore) addition the blower could compensate for any slight variation in temperature and composition of the iron originating from the mixer.

Apart from temperature, other considerations—such as bath depth and the use of ore—come into the picture in attaining low-nitrogen steel; thus, at the basic Bessemer works at Corby, a modified process has been developed in which the converter is widened to give a shallow bath of metal and the scrap is replaced by equivalent additions of iron ore or scale. By these measures the nitrogen content is lowered to about half the value obtained in the ordinary process, whilst at the same time the phosphorus is substantially lower.

Nitrogen alters the properties of the steel very considerably; its effect is not always harmful and so the nitrogen content is adjusted according to the use to which the steel is to be put. It is not a matter of great interest to steelmakers what these properties are, but it is of utmost importance to know that here is a process where the nitrogen can be supplied to order between 0·008 and 0·018%.

The following steels are made by the basic Bessemer process: Tube steels, drop-stamping steels, wire-drawing steels, and deep-pressing steels. The analysis of the steels made range as follows: Carbon, 0·04–0·20%; silicon, trace; manganese, 0·25–0·95%; sulphur, 0·04% (maximum); phosphorus, 0·040% (maximum); nitrogen, 0·010% (maximum). The principal products are, however, dead-soft steels.

The Sub-Committee suggest that there seems to be no reason why the basic Bessemer process could not be used for other purposes, after suitable controlled experiments. The chief objection to making medium- and high-carbon steels by this process is the low carbon content to which the steel must be blown, resulting in a correspondingly high iron oxide content of the blown metal. The reaction of this oxide with the killing agents added to the ladle was in the old days considered to be harmful. However, so many hundreds of thousands of tons of rail, ship, and other steels have been made by the basic Siemens high-P_2O_5 slag process, in which the carbon is reduced to a figure nearly similar to that experienced in the converter, that it is difficult to believe that any difference in quality would exist. The Sub-Committee thus feel that in view of the improved control of the modern basic Bessemer process as practised in Britain many of the old prejudices are now without any foundation in fact, and that the metallurgist has now to use an open mind when choosing between basic Bessemer and open-hearth steel.

The Acid Process.—The discovery of this process, in 1856, by Henry Bessemer led to the production of millions of tons of steel without any essential modifications of the principles originally laid down. The peak production in this country was reached about 1889–90 when an output of some 1¾ million tons per annum was reached, representing about 48% of the total steel output. Since then production has declined from many causes, a major one being the shortage of suitable raw material which largely accounts for the fact that to-day only one plant operating this process is working in Britain[*]. This is centred on the Cumberland ore field, which yields an exceptionally pure form of hematite from which iron of suitable quality can readily be made.

This bulk-production acid Bessemer steel plant is operated by the Workington Iron and Steel Co. Ltd., having been conducted there since 1876. An entirely new plant replaced obsolete plant in 1934, the new plant consisting of two 25-ton vessels. Blast furnace casts vary from 60 to 110 tons and are transferred in suitable ladles to an inactive mixer of 400 tons capacity. The hot metal from the mixer is transferred to the converters (which are worked alternately), each charge being weighed. Blowing continues until the appearance of the flame indicates the final elimination of the carbon, when the vessel is turned down. Excessive temperature, indicated by the appearance of the flame supplemented by the blower's experience with the previous blow, is corrected by means of weighed scrap additions during the blow. Low temperatures, when they occur, are corrected by additions of ferrosilicon.

Experiments in which light-sensitive cells have been utilised for the determination of comparative temperatures and of the end point of the blow have been conducted over a period of ten years, but the results obtained with such instruments have only confirmed the blower's acquired skill. Temperature recording was not regularly practised until recently, but immersion pyrometry has now come into use.

The range of steels made at Workington extends from dead-soft rimming qualities through normal rail steels to those containing 1·0% of carbon. In addition, manganese steel of 13·0% manganese content is also made. They are eminently suitable for certain special purposes, but the bulk of the production goes to the making of rails, fishplates, sleepers, and screwstock. The free-cutting qualities of the steel produced for the latter application make the material particularly suitable for the purpose.

The exclusion of Bessemer steel, whether of basic or acid origin, from certain specifications is a matter which would appear to require re-opening. It has been agreed that there is no question as to the ability of Bessemer steel to pass present tests, but there exists a fear that such steel suffers from a lack of uniformity; acceptance to specifications from which it is at present excluded would probably only follow a thorough and complete series of tests conducted over a period of twelve months or more by representatives of the appropriate organisations. Much of the prejudice which exists against both basic and acid Bessemer steels is based on the fear of over-oxidation of the iron resulting from the apparently empirical methods of control. There would appear to be a real need for research into the physucal chemistry of the process, as it is felt that a complete understanding of this would dispel the false opinions held by those who have previously condemned it.

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[*] There are also three 3-ton bottom-blown acid converters at the works of Messrs. Hadfields, Ltd., and a number of surface-blown converters in other works making steel for foundry castings.

The Surface-Blown Process.—Visits to the plants of Edgar Allen and Co. Ltd. and Samuel Osborne and Co. Ltd. by the Sub-Committee enabled the following conclusions to be drawn in connection with the surface-blown converters inspected :—

(1) There is no trouble as regards nitrogen absorption, even with steel temperatures of up to 1,700° C. ; the normal nitrogen contents vary between 0·004 and 0·008%.

(2) In both works visited the slag is dealt with by rabbling-off the excess or holding it back with a rod. If the slag is very liquid an artificial brick tap-hole is used ; in contrast to large-scale acid Bessemer practice this can be done without difficulty.

(3) The neatness and precision of the process made the Sub-Committee reflect if the method could not be carried out on a larger scale and utilising a basic lining, and it is suggested that this is a study which the British Iron and Steel Research Association might be interested to follow up.

The process is used almost entirely for foundry work, but in the past it has been employed for a very large variety of small ingots ranging from mild steel to 4% chromium steel. The staffs of both works said that if business should tend that way no difficulty at all would be experienced.

Multiplexing Processes.—This subject is considered under several headings, such as, general survey of duplex practice ; advantages and disadvantages of duplex working ; American duplex practice ; German duplex practice ; a surface-blown converter multiplex practice ; Bessemer electric duplexing ; and other duplex processes.

Bessemer-open-hearth duplexing is claimed to have originated in Neuberg, Styria, in 1872, but its first wide application and development occurred in the United States. The plentiful supplies of rich iron ores of low-to-medium phosphorus content and the low availability of steel scrap in the main iron and steel making districts of the Middle West provided a set of conditions eminently suitable for duplexing by acid Bessemer and basic open-hearth processes. Originally the finishing leg was carried out as a continuous operation in tilting furnaces in which about one-third of each charge was carried through to the next heat. More recent practice in the case of tilting furnaces is to cut down the amount of metal and finishing slag carried through to the following charge, in some cases even to the point of completely emptying the vessel. Suitable technique has also been devised for the fixed furnaces now used extensively for the finishing of acid-Bessemer/basic-open-hearth duplex heats. Modifications of these methods have been found advisable in the duplexing of basic iron produced from the higher-phosphorus ores of Alabama, but in the United States as a whole the converters used are exclusively acid-lined and dephosphorisation is carried out entirely in the second, or open-hearth, leg of the process.

American duplex methods as a class are essentially " all-liquid " ; that is, they do not normally employ steel scrap as an essential component of the open-hearth charge. Consequently, the steel produced is usually characterised by a low content of residual elements. This method has been applied extensively in other parts of the world, notably India and South Africa, where conditions relative to raw materials are closely akin to those obtaining in the Lake-ore-consuming area of the United States, namely an abundance of rich ores of low-to-medium phosphorus content and a relative dearth of steel-making scrap.

German duplex practice was developed under conditions and for reasons entirely different from those obtaining in the United States. German steel-making practice has been built up on the principle that phosphoric irons are handled by the Thomas converter, and only low-phosphorus materials are charged into the basic open-hearth. In this way the elemental phosphorus is harnessed and used to sustain the former process, for the production of structural, rail and similar commercial steels in bulk. The basic open-hearth, with a metallic charge comprising 15–30% of stahleisen of low phosphorus and high manganese contents, and 70–85% of scrap, is thus enabled by reason of light metallurgical load, slag of low basicity and weight per ton of steel, etc., to achieve a high standard of attainment with regard to output, thermal efficiency, operating costs, and steel quality. Germany's adherence to these principles, even in the face of the serious raw materials difficulties of the recent war, has indeed been remarkable. During the period between the wars the availability and composition of home and foreign iron ores and of steel scrap facilitated a balanced scheme in which the production of basic open-hearth, Thomas, and electric arc steels was in the broad ratio of 10 : 7 : 1. Working the straight processes, this would have left the basic open-hearth with a deficiency of scrap and stahleisen ; the gap was filled by the production of a substantial tonnage of duplex steel, with the Thomas converter functioning essentially as a producer of molten synthetic scrap of low phosphorus content. Thus was the principle of low-phosphorus materials only for the basic open-hearth maintained, in the case of conventional duplexing.

The layout of many German steel plants has been designed to facilitate the handling of blown metal from Thomas converters to basic open-hearth furnaces and use of these facilities ranged from constant bulk production at such plants as Mannesmannrohren Werke (Huckingen) and G.H.H. (Oberhausen) to opportunist use according to raw materials availability, specification and market demands, etc., at many other works. In the case of the newest integrated plant in Germany—the Hermann Göring Works at Watenstedt—the steel works layout is designed to facilitate all possible combinations of Thomas, basic open-hearth, and basic electric-arc processes.

In contrast to conventional American practice, German duplexing is not " all-liquid," small proportions of stahleisen and scrap being usually employed as essential constituents of the open-hearth charge. As the scrap is principally return mill scrap from Thomas or duplex production, German duplex steel still retains the feature of comparative freedom from residual elements.

Use of the Bessemer converter similarly to provide what is literally molten synthetic scrap to the electric-arc furnace has also been made on a fairly extensive scale, particularly in the United States and Germany.

Acid- or basic-Bessemer basic/open-hearth duplexing is particularly suitable for the bulk production of qualities of steel normally made in the open-hearth, and has the advantage that the productivity of the finishing leg of the process is increased two to four fold as compared with straight cold-pig or hot-metal/scrap working. There is thus, in integrated works where the requisite supplies of hot metal are available, considerable economy in the capital commitment, ground space, etc., required for a given productive capacity of open-hearth or equivalent steel. These economies go beyond the steelmaking department proper, since the substantial shortening of tap-to-tap times smooths the flow of hot ingots to the mills, thereby reducing the soaking-pit capacity required for a given throughput tonnage.

The nitrogen content of Bessemer/open-hearth duplex steel appears to lie generally between that of straight Bessemer on the one hand and straight open-hearth on the other, but naturally depends upon the particular practice adopted.

The chief disadvantages of Bessemer/open-hearth duplexing are that it involves two conversion costs and adds to the relatively low yield of the pneumatic leg of the process the further loss involved in the open-hearth. Under certain economic conditions, and particularly those obtaining in America, India, etc., it is, however, contended that the high production rate of the process is capable of offsetting the above adverse factors, but in times of slackened demand the relative inflexibility of the acid-Bessemer/large-tilting-furnace version in particular must be set down on the debit side.

Originally, American acid-Bessemer/basic-open-hearth duplexing was developed around the use of the pneumatic process to furnish desiliconised and partly decarburised metal to large tilting furnaces of the Talbot type. A typical combination was two or three 20-ton converters and three 200–250-ton tilters. Apart from week-end fettling, repairs, etc., operation was continuous in that only one-half or two-thirds of the open-hearth charge was tapped and teemed into ingots, the balance of the metal and the whole of the finishing slag being carried through to the next heat. More recently the proportion of metal carried through has tended to fall, and in two examples of modern American duplex practice only a small pool of metal plus the finishing slag is left behind in the one case, whilst in the other complete emptying, or "dry bottom," practice is used.

The plant and practice employed at Mannesmannrohren Werke, Huckingen, probably provide the best example of German duplex working. The basic Bessemer plant, installed in 1929 and since enlarged, comprises two 1,000-ton barrel-type inactive mixers and five converters of 30 tons capacity. The open-hearth plant consists of six fixed furnaces of 75 tons nominal capacity, designed for mixed-gas or producer-gas firing. Four of the furnaces are of Maerz design, with a bath area of 40 sq. m. (430 sq. ft.), whilst the remaining two are of an older type, with conventional port arrangements. All six open-hearth furnaces have Crespi hearths. In normal times the rebuilding schedule allowed five open-hearth furnaces to be worked, and four of these usually operated the second leg of the duplex process, whilst the fifth worked on a high-percentage-scrap/cold-stahleisen charge.

Between 80 and 90% of the tonnage classed as open-hearth was made by the duplex process and comprised round and square ingots for pilgering, sq. ingots for rolling into tube rounds, and cast slabs ranging from 600 to 40,000 kg. in weight for direct rolling into plates. All the open-hearth output at Huckingen, whether rimming or killed steel, was uphill-teemed, chiefly into narrow-end-up square or slab moulds. Part of the output of blown metal from the basic Bessemer shop was used for duplexing in the electric-arc furnaces, of which there were two (12 and 25 tons capacity), charging 20 and 40 tons, respectively, when working duplex.

Although Bessemer electric duplexing can scarcely be regarded as a well-established process, it has been practised successfully in most European countries and in the United States, both the acid and the basic Bessemer converter having been used in conjunction with the electric furnace. The claims made are that the advantages of the electric furnace, namely the unique control of steel refining and ability to make alloy steels, are gained, together with a high production rate and a lower electric/power consumption per ton of steel.

In this country, Bessemer/electric duplexing has not been adopted for routine production of steel, but the method has been well tested out at the Corby works of Messrs. Stewarts and Lloyds, Ltd., and at the works of the Workington Iron and Steel Co., Ltd., certain experimental casts representing wide extremes in steel making practice, viz., soft rimming-steel and high-carbon chromium-molybdenum steels having been made. The steels produced in both cases were satisfactory. Details of these experiments, together with furnace sheets for typical casts are given in the Report.

In addition to true methods of duplexing which link in sequence conventional steel making processes and plant, there are others which, whilst employing only one main process carried out in furnace or converter, might be regarded as duplex in the metallurgical sense in that a definite refining operation is carried out in the casting ladle. It might be contended that addition of ferro-alloys or other finishers to the casting ladle would bring any steel making process into this category, but for the purpose of the review the criteria given in the Report are that the slag added to the ladle must be premelted and its composition must be such as to enable it to perform a definite metallurgical function complementary and/or corrective to that of the main process, and particular reference is made to the Perrin process. As applied to fully blown metal produced by two-slag practice in the basic Bessemer converter, this process facilitates attainment of very low sulphur, phosphorus and oxygen contents, with a high standard of cleanness. Rigid exclusion of the second phosphoric oxidising slag from the tapping ladle is effected by building a "lime bridge" across the mouth of the converter, which is then tilted quickly to give the maximum turbulence and intermixing of steel and premelted lime/alumina slag. Any necessary additions of ferro-alloys, aluminium, etc., are made to the stream during transfer from converter to ladle. Even without the addition of metallic deoxidisers a rimming composition leaving the converter is completely killed by the action of the slag alone. This version of Perrinising is therefore suitable for the production of killed steels only, and appears particularly appropriate in the case of low-carbon stabilising steels required to have low susceptibility to strain age-hardening. Nitrogen contents range from 0·008 to 0·015%, depending primarily upon temperature and slag conditions in the pneumatic leg of the process; churning with the lime/alumina slag appears to have little influence. A considerable tonnage of alloy steels (nickel–chromium, chromium–molybdenum, etc.) was produced by this process during the early part of the recent war.

Foreign Bessemer Practice

In this section more detailed information is given of practice on the Continent notably in Sweden and Germany. The Swedes were early in the field in the development of the Bessemer process and claimed that they led the world in the production of high-quality Bessemer steel. In Germany, during the past 25 years particularly, there was a slow but steady setback in the relative progress of the Thomas process, but a certain minimum tonnage of Thomas steel had to be produced solely to provide the plants at the next stage of manufacture with energy. Using the process as a source of energy did not play a dominant role in Britain, with its preponderance of open-hearth production, or at the French, Belgian and Luxemburg works in the Minette basin. It was not until the recent war, particularly because of the enormous growth in the Thomas capacity in the then occupied territories that it became a matter of urgency to use high-grade Thomas steel for items which were previously made only of open-hearth steel, such as shell steel, ships' plates, deep drawing steel, etc.

A review is given of American plants as a result of a visit by a member of the Sub-Committee. The most striking thing about American Bessemer plants was the enormous production of a comparatively small shop. The equipment is designed to handle the tonnage easily and without one operation interfering with another. Working conditions are standardised to a considerable degree with a resultant benefit in regularity of product. The past fifteen years has led to improvements in process techniques which have resulted in greater uniformity in quality and an extension in the uses of Bessemer steel.

In this section considerable attention is given to descriptions of plants on the Continent and in America.

Future Bessemer Practice

In this section some suggestions are made for future developments in Bessemer practice. It is considered, for instance, that recent developments on the Continent with regard to (1) the use of oxygen in the blast; (2) the modified large side-blown converter, and (3) the double blowing of the metal, merit investigation in this country.

The main advantages claimed for the use of oxygen in the blast are as follows :—

(i) Low-silicon irons can be used.
(ii) More scrap can be charged.
(iii) Low-nitrogen steels can be made.

The main disadvantage is the greatly increased wear of the tuyères.

The claims for the modified large side-blown converter are similar to, though less spectacular than, those made for the use of oxygen in the blast.

The advantages claimed for double blowing of the metal are :—

(i) Increased production.
(ii) Increased yield.
(iii) The obtaining of lower phosphorus and nitrogen contents.

The Sub-Committee also consider that research into "catching carbon" might be worth while. They advocate this not from an economic point of view, but in order to extend the scope of the basic Bessemer if the occasion arose. The chief difficulty of such a process is that normally no true slag is formed in the basic converter until the carbon is down, as is evidenced by the presence of large quantities of solid lime. The addition of fluxes or synthetic slags melted in an electric furnace and added during the blow might extend the range of steels that could be made by this process.

Another matter requiring elucidation is the German claim that an immiscible phase high in oxide exists in the slag during and at the end of the after-blow. They submit that the final melt is not in equilibrium with the phosphate slag as denoted by their chemical compositions.

Finally, in order to ascertain the full extent of the uses to which Bessemer steels may be put it is suggested that the British Iron and Steel Research Association should conduct an investigation in which ingots made by the Bessemer process would be manufactured into products which are not usually made from Bessemer steel.

The Report concludes with descriptions of a number of British plants and the methods employed in operating them.

New Director of the N.P.L.

The Lord President of the Council has appointed Professor E. C. Bullard, M.A., Ph.D., F.R.S., Professor of Physics in the University of Toronto to succeed Sir Charles Darwin, K.B.E., M.C., Sc.D., F.R.S. as Director of the National Physical Laboratory. It is expected that he will take up the appointment in January, 1950.

Professor Bullard, who is forty one years old, was educated at Repton and Clare College, Cambridge, where he studied physics. In 1931, when the college decided to create the post of demonstrator in geodesy, Professor Bullard was appointed and worked out improved methods of recording the times of the swing of pendulums for determining the force of gravity.

Elected to the Smithson Research Fellowship of the Royal Society in 1936, Professor Bullard continued to work at Cambridge and took up geophysical methods of determining the geology of the earth's crust. This work involved exploding a charge in a hole 12 ft. deep and detecting the arrival of the vibrations at various points away from the explosion, from which the depth of the palaeozoic floor can be deduced.

When war broke out in 1939, Professor Bullard joined the Admiralty. His most important work was on the de-gaussing of ships against the magnetic mine and he was also concerned with measures against the acoustic mine. From 1944 to 1945 he was Assistant Director of Naval Operational Research. He was elected a Fellow of Clare College in 1943 and when the war ended again took up his geophysical work until 1948, when he was appointed Professor of Physics at Toronto University. He was made a Fellow of the Royal Society in 1941.

Steel-making for Castings

By E. C. Pigott

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Steel, the product of some of our best inward qualities, is also the most important material of our outward civilisation. It is not only in the melting shop that a knowledge of steel-making is necessary; a grasp of at least the more important aspects of manufacture is indispensable to a correct use of the metal and it is partly with this viewpoint in mind that the author discusses the various processes by which steel suitable for castings is produced.

STEEL is a complex substance and the methods by which it is made are many and varied. Although several of the processes originated in this country, certain of them, such as the basic Bessemer process, owe much to their development abroad. The major part of the country's steel output is, of course, in the form of wrought products, but the steel foundries are now producing in the neighbourhood of a quarter of a million tons of castings annually. In the manufacture of steel for castings, use is made of almost the whole range of steel-making processes and it is proposed to deal with some of the salient features of each of them.

Only in certain respects are wrought steels superior to annealed steel castings, especially where the castings are the product of sound foundry practice and experimentation, and are well designed. Hot-working certainly improves steel in the direction of working, but actually impairs it in the transverse direction. Moreover, wrought steel has not the creep strength of the steel casting. In respect of corrosion-resistance, they are about equal. Castings are superior to fabricated structures made of forged or rolled components, being more uniform in composition and stresses. For complicated shapes and sections the inherent advantage of castings remains unchallenged; any shape too intricate to be made by rolling or forging must be cast.

Steels of certain compositions are unsuitable for forging or rolling and they, too, must necessarily be cast to shape. For example, most manganese steel components used in crushing and dredging, and as switch points, etc., are cast. Where physical properties permit, it is often more economical to cast large simple shapes, and the same applies to small simple shapes required in quantities too limited to justify the making of forging dies. Castings range in weight from a few ounces up to a hundred tons or more and the almost limitless range of cast components includes locomotive and other railway parts, general machinery, valves, fittings, and parts for cars, tractors and cranes.

Steel casting is one technique which underwent much war-time development, and that it continues rapidly to gain ground is shown by the popularity of large cast-gear wheels and other large high-duty castings. In speciality, repetition and jobbing foundries alike, a very high standard is maintained.

Steel for castings and ingots is made from pig iron, the weak, impure product of the blast furnace. Four-fifths of British steel is made by the Siemen's open-hearth process, most of the remainder being produced by means of the Bessemer converter (7%) and of the electric furnace (4%). All these various processes are employed for producing molten steel for castings, but normally, the larger castings are made by means of the open-hearth furnace or of the Bessemer converter.

A very extensive variety of castings is produced by means of the small, side-blown converter, and of the electric arc furnace. For the production of small castings in alloy and other high-duty steels the induction, oil-fired crucible and Huntsman's crucible processes are used, the induction furnace having largely supplanted Huntsman's original crucible process. Most alloy castings are from electric arc and high-frequency steel.

In choosing a process much depends on the regularity of melting. Arc and induction furnaces and converters lend themselves to intermittent operation, differing from the open-hearth furnace in this respect. The open-hearth method is also the least flexible. Electric methods produce the best steel but at higher cost and are most suitable for moderate or small works. Converters excepted, all processes utilise steel scrap extensively. Most foundry converters are of the small side-blown type, which furnishes the hotter metal necessary for castings.

Common to all steel-making processes is the removal, by oxidation, of the bulk of the impurities contained in pig iron. These impurities, existing in the form of five different elements, carbon, silicon, manganese, sulphur and phosphorus, amount in all to 5 or 6%. At every turn refining is dominated by the question of combined oxygen, the elimination of which converts the original iron ore into pig iron and the generation of which later converts the pig iron into steel. Steel-making is impurity-oxidation.

THE BESSEMER PROCESS

The Bessemer converter, which converts pig iron into steel, is a pear-shaped vessel of mild steel lined with refractory material. A capacity of 15–25 tons is normal, but much smaller sizes are also used. The vessel is composite, consisting of three distinct parts, the body, the nose, and the bottom section, riveted together.

Depending on the type of lining material and the kind of pig iron, the process is either basic or acid. Through the flattish base are numerous holes or tuyères, formed in specially shaped bricks. Being mounted on trunnions, the converter is readily rotated about its axis as required at various stages of the process. After previous heating, it is charged with pig iron in the molten condition. Through the tuyères, a blast of cold air supplied by a blowing engine is forced into the molten metal, with the result that the impurities are burned out, the generation of heat internally keeping the purified metal molten. All the heat required by the process is self-generated in this way, no external heat being applied. Oxides of the impurities combine together to form a fluid floating slag, the gases escaping at the open end.

Since blowing of the charge normally lasts less than half an hour, precision control is a difficult matter. After blowing, the molten metal contains injurious quantities of iron oxide, etc., and would be weak and brittle. Accordingly, ferro-manganese is added to deoxidise and recarburise the metal.

In foundry work the main application of Bessemer steel is in the making of mild grades of carbon-steel castings. In the alloy field the Bessemer is best suited to the making of manganese steel castings, since alloy scrap cannot be used economically by the process. For castings the acid process is generally used.

Acid Bessemer Process

In the acid process the vessel is lined with rammed high-grade ganister subjected to prolonged drying and baking. Silica brick undercourses have been used. Particular care is required in lining the bottom section which is attacked so rapidly as to survive not more than about 30 heats, as compared with a body-lining life of 1,000–2,000 heats. After each blow the lining is patched where necessary and more thorough repairing is carried out each week-end.

Both in number and size the fireclay brick tuyères vary from plant to plant. A total tuyère area of 4 sq. in. per ton of charge, and a blast of 20–24 lb. per sq. in. are suitable.

Charge.—Most of the necessary heat generated during the blow is provided by the carbon and silicon in the iron. The optimum content of silicon is 2%, larger proportions leading to too hot a blow, and smaller amounts to a dull blow. Contents below 2% may be raised by adding ferro-silicon (12–14% silicon) before or during the blow. A low manganese content is usual. Careful selection of the pig iron is essential, in order to provide suitably low contents of sulphur and phosphorus, both of which must be even lower in metal for castings than in metal to be wrought. Owing to the concentration effect arising from the blowing loss of part of the iron the sulphur and phosphorus contents increase slightly. Usually, the loss of metal is between 12 and 16%, but in some cases it may be as high as 20%.

The Blow.—Before raising the charged converter, the blast is started. Passage of the fine streams of air through the molten metal instantly sets up chemical oxidation of the constituents of the bath: the blow lasts 20 minutes or so.

Most of the silicon must be eliminated during the early stages of the blow, before the removal of carbon becomes vigorous. Silicon is more readily removed at relatively low temperatures, and it may be necessary to turn down the vessel and to cool the metal somewhat by adding steel scrap. Too hot a blow results not only in the retention of too much silicon, but also in badly over-oxidised metal.

Probably the first element to undergo oxidation is manganese, which is removed rapidly. Oxidation of the carbon also commences at an early stage, the removal rate increasing rapidly as the blow proceeds. Iron undergoes partial oxidation from the first, much iron oxide being ejected. The carbon, as carbon monoxide, burns at the converter mouth, while the oxides of silicon and manganese pass into the slag.

The Flame.—Converter control depends largely on observing the nature of the flame issuing from the mouth of the vessel. On turning up the charged converter a heavy shower of sparks is ejected. In about 4 minutes the more vigorous expulsion of silicon and manganese extends the flame, and in a further 4 minutes it becomes violent and brilliant, with forceful sparking. This phase, known as the boil, is one of carbon removal.

After 18 or 20 minutes from commencement of the blow, the flame becomes less luminous and less violent, and within a short time, finally recedes. At this point, which must be observed with great accuracy, the vessel is immediately turned down.

Sometimes a spectroscope is used as an aid in following the progress of the flame. As the temperature rises, after about 4 minutes' blowing, bright green carbon lines predominate, while towards the end of the blow, the spectrum fades, the green lines finally vanishing.

The blown metal has the following approximate percentage composition: carbon 0·04–0·08, silicon 0·02–0·07, manganese 0·01–0·08, sulphur 0·04, phosphorus 0·04. To end the blow prematurely would be to produce steel containing too much carbon, silicon and manganese. On the other hand, any delay would cause excessive oxidation of the iron itself.

Large amounts of dissolved iron oxide are present in the blown metal, which must be deoxidised and also recarburised to the desired carbon content. Accordingly wet lumps of ferro-manganese (80% manganese, 6–7% carbon) and/or spiegel (12–20% manganese, 2–4% carbon) are thrown in with sufficient force to ensure rapid penetration of the slag. Normally, the loss of these additions is of the order of 20–30%. Small amounts of broken glass may first be added to produce a thinner slag.

Ferro-silicon and other alloys may be added either in the converter or in the ladle. In usual practice, the metal is held in the ladle for a few minutes before pouring, casting temperatures much higher than 1,580° C. being avoided.

THE TROPENAS PROCESS

In the production of light castings, the Tropenas side-blown converter is used very extensively, the metal being exceptionally hot and fluid. The vessel is of 1½–3½ tons capacity and consists of a steel shell lined with silica bricks and ganister and mounted on two substantial elevated trunnions, one of which is hollow for the passage of cold air to a wind box. The base has the shape of a truncated cone and is detachable.

Charge Metal.—The charge consists of molten cupola metal at a temperature of 1,400° C., or more, and it is necessary to maintain reasonable control of the composition of this metal. In the case of the first charge of the day, the silicon content should be about 1·8%, but as the cupola and converter become hotter during the day this should be reduced to about 1·2%. Normally the manganese content does not greatly exceed 0·6%. Phosphorus must be kept below 0·05%. Under average melting conditions, the cupola metal has a sulphur content exceeding 0·07% and is desulphurised by means of soda ash in a transfer ladle.

Converter Operation.—Adequate preheating of the vessel to a white heat after re-lining or patching is of primary importance. When the cupola is about to be tapped, the hot vessel is turned nose-down and the coke removed. The desulphurised cupola metal is then charged, the weight of the suspended ladle and metal being noted before and after charging.

The Blow.—The tuyère plate is attached and the blast is fed through the tuyères at a pressure of 3½–4 lb. per sq. in. The vessel is then turned back to an angle of 15° short of the vertical, when the surface of the metal should be ½–1 in. below the tuyères. There is an upward shower of star-like sparks and a distinct glow over the tuyère side develops into a small unsteady flame which gradually gains in luminosity and height. Within 8 minutes or so the flame should reach a height of 2 or 3 ft. Throughout the following 4 minutes, the air pressure is carefully controlled in order to restrict the height of the flame and to prevent "boiling." About 12 minutes from commencement of the blow the bulk of silicon and manganese will have been oxidised into slag.

The silicon flame then falls perceptibly, to be replaced by an intensely white flame from the fierce oxidation of the carbon. During this boil period which lasts 6–9 minutes the blast is kept at 2¼–2½ lb. per sq. in., and the vessel is turned "into the wind" until 11° from vertical. Eventually the flame rises rapidly to the peak, marking the fining period, of about 2 minutes' duration. In order to obtain a fluid slag which will allow ready penetration of the blast, it is good practice at this stage to add broken glass (10 lb. per ton). Finally, the flame is seen to fall quite distinctly, and when it is barely a foot in height the vessel is turned forward out of the wind and the blast stopped simultaneously.

An average percentage composition of the blown metal is carbon 0·06, silicon 0·03, manganese 0·01, sulphur 0·03, phosphorus 0·05. Deoxidising additions of ferro-silicon and ferro-manganese are then made, and, during the tapping, aluminium is used for further scavenging at the rate of 2 lb. per ton.

The higher temperature of Tropenas steel permits the wider use of green sand moulds for castings.

ELECTRIC ARC PROCESS

A most important way of making steel for foundry purposes is by means of the electric arc process, used for rapidly producing many carbon and alloy steels of best quality and uniformity. Steel for castings is made in the arc furnace wherever the advantage of sounder, cleaner steel offsets the high cost of production. Positive composition control makes the process popular where special and complicated analyses are required.

Usually, the furnace lining is basic in character, permitting the removal of sulphur and phosphorus, but acid-lined furnaces are used on a growing scale, a trend more marked in the United States where acid practice predominates in steel foundries. The basic process is the more costly, takes longer, and calls for closer control, but the product is cleaner than acid electric steel.

Temperatures may be higher than in the non-electric processes, and, even in the case of alloy steels, any required degree of fluidity is available, a factor of importance in making steel castings, especially those of thin section. Since these high temperatures impart slag-fluidity, even when much lime is present, sulphur removal is practically complete, and the use of cheap scrap is permissible. Alloy additions suffer little or no loss, and ladle additions are seldom necessary.

Reducing conditions, easily maintained, dispose thoroughly of dissolved oxides and gases and a distinctive feature is the absence of contaminating sulphurous gases. The process is applied extensively to the making of high-chromium and high-manganese steels, the basic furnace melting high manganese scrap with small loss.

Furnace.—Arc furnaces vary in capacity from 35 cwt. to 35 tons or more, but in foundries only the smaller sizes are used, up to 6 tons. These are of tilting construction and are invariably fitted with a removable roof, which is replaced with a spare roof when necessary. The heat required for melting is generated by electric arcs struck between two or more graphite electrodes and the metal charge. Each arc generates a local temperature of some 3,400° C. The various types of furnace differ in arc details. In the Héroult type, the most popular, there are three electrodes and the current traverses the metal surface, returning to the transformer. Modern developments of this type are typified by the Siemens-Schuckert furnace. In the Greaves-Etchells type, the current travels via the molten bath to a copper plate attached to the furnace bottom. Irrespective of type, three phase 50 cycles alternating current is used. Transformers, electrode holders and roof coolers are fed with water at a pressure of 30 lb. per sq. in.

Basic Process

In the basic process, limey slags are used and the lining consists of rammed dolomite or magnesite or a blend of both. Boiling anhydrous tar serves as bond during ramming, while a mixture of basic slag and crushed electrode is incorporated to provide a bond at high temperatures.

In order to remove phosphorus, silicon and carbon to the required extent, oxidizing conditions are first maintained; the bath is then deslagged and recarburised and lastly desulphurising is carried out under reducing conditions. The earlier chemical changes are identical with those in the open hearth process.

Charging and Melting.—The charge consists of steel scrap and practically any grade can be used, though average sulphur and phosphorus contents should not exceed 0·1% each, and a proper balance should be struck between heavy and light scrap. Alloy scrap suffers only a small melting loss. With the electrodes raised, charging is carried out quickly in order to retain the initial heat in the furnace. The larger pieces are charged first and part of the charge is held over until the first portion is practically molten. The current is switched on, and the electrodes are lowered until arcs are struck. When a pool of molten metal has formed under the electrodes, unmelted scrap is pushed towards the centre of the furnace. Melting is promoted also by occasionally adjusting the height of the electrodes. As melting proceeds, slag additions are made, burnt lime being added together with small amounts of fluorspar and sand to provide the proper fluidity.

Oxidising.—Owing to the particularly ready formation of iron oxide, the slag largely oxidises and absorbs the phosphorus, carbon and manganese, ordinary atmospheric oxidation having removed most of the silicon. It is usual to add further iron oxide in the form of iron ore or scale. When entirely molten, the metal is well rabbled and then sampled for a fracture test, and also for analysis if alloy scrap has been charged.

Phosphorus is removed most readily when the temperature is relatively low. Sufficient phosphorus having been removed, the temperature is raised so as to promote oxidation of the carbon. The aim should be to reduce the carbon content to 0·05–0·10%. Higher contents point to inadequate phosphorus oxidation, while lower contents indicate over-oxidation of the bath, as shown also by a low manganese content, say less than 0·05%.

Slagging and Recarburising.—With the contents of phosphorus, carbon, silicon and manganese much below those required in the finished steel, the black impure slag is poured off by slightly tilting the furnace, removal being aided by skimming with rabbles. The bare metal is recarburised by adding ferro-silicon and ferro-manganese and just short of the amount of anthracite or broken electrode which would provide the final carbon content. The floating coal or electrode is worked into the metal by means of a long wooden pole, but even so not more than half is assimilated. Final adjustment of the carbon content is effected by adding low-phosphorus pig iron. If only a small carbon increment is required the coal or broken electrode may be omitted. In either case the carbon content is checked by means of fracture tests and chemical analysis.

Reducing and Desulphurising.—Sulphur and oxides are now liberated from the molten metal, their elimination being followed by visual examination and actual analysis of bath samples taken at frequent intervals. Successful desulphurising calls for a high temperature and a highly basic white slag, of a reducing character, the sulphur being removed as calcium sulphide. The white reducing slag is formed by adding lime and fluorspar and covering with sufficient high-grade ferro-silicon and crushed anthracite, coke or electrode. Slag and metal are stirred into contact and metallic oxides in the bath are rapidly reduced by the calcium carbide in the slag. Reducing conditions are maintained by adding more coal or coke until sufficient calcium carbide is present to generate gas when a cold slag sample is immersed in water. Excessively high bath temperatures have an adverse effect on the metal.

Final Additions and Tapping.—With the exception of titanium and vanadium, which should be added as late as possible, any required ferro-alloy additions are made as soon as the bath is virtually deoxidised. Final deoxidising is carried out immediately afterwards by adding small amounts of ferro-silicon, ferro-manganese, and the like. When high manganese steel is made the ferro-manganese may be pre-melted in the cupola ; the loss of manganese is smaller than in other steel-making processes.

Over a period of half an hour or so during which deoxidisation products rise into the reducing slag, the temperature is raised until correct for tapping, as shown by an immersion pyrometer or by spoon tests.

High carbon and alloy steels should be tapped under a carbide slag with the carbon content of the metal slightly below requirements, to allow for absorption. The electrodes are raised, the furnace is tilted, and the metal is poured into the ladle at such a rate that the slag level is kept above the tap-hole. Strongly preheated bottom-pour ladles are very suitable. Small ladle additions of ferro-titanium, aluminium or calcium silicide may be made to assist scavenging, and time is allowed for slag particles to rise to the surface of the ladle metal. Normally, sulphur and phosphorus contents in the finished steel are of the order of 0·01–0·015% each.

Where the charge consists of selected electric furnace scrap, the oxidation stage may be omitted, the finished steel then having the lowest oxygen content of all processes.

In the production of heat-resisting castings, the oxidation period is followed by the gradual addition of ferro-chromium and then of ferro-silicon, which extracts chromium from the slag. Alternatively, the charge may consist of low-carbon and stainless-steel scrap and chromite ore, in which case crushed ferro-silicon and aluminium are added as soon as the carbon is sufficiently low.

Repairs.—As soon as the furnace is empty, residual steel having been splashed out, fettling is begun. Any large holes are filled with a mixture of basic slag (one part) and dolomite (ten parts). Major repairs are undertaken at the first indication of redness on the furnace shell.

Acid Process

In the acid process, the furnace is lined with silica bricks, the hearth consisting of a mixture of sand, ganister and iron oxide, rammed down in successive 2-in. layers. The purifying procedure resembles that in the acid open-hearth process.

Charging.—High-grade steel scrap normally makes up the charge, foundry scrap often predominating. Sulphur and phosphorus are not removed and so should not exceed an average of 0·04% each in content. Preferably, the average carbon content should be about 0·05% higher than the percentage required in the finished steel. Any pieces such as plate punchings are formed into a compact mass in the furnace and covered with the heavy and bulky scrap, with the remainder of the charge on top, the whole being heaped centrally in a mound.

Oxidising.—Care is taken to melt the charge with little oxidation, but through the agency of iron oxide from rust and scale, part of the carbon and considerable amounts of silicon and manganese become oxidised. When the charge is completely molten, sand and broken glass are added to form a slag. The carbon content is lowered to a point much below the desired final figure by carefully adding at intervals lumps of selected iron ore in small quantities. Excessive oxidation is avoided.

Limestone is added to the slag to provide the right consistency and to restrict the iron-oxide content. Loss of carbon may be gauged not only by the appearance of fractured metal samples, but also by watching the character of the slag, which gradually loses iron oxide.

Refining.—Refining is effected by prolonged heating at a high temperature and consists mainly in the removal of the non-metallics formed by the oxidation of silicon and manganese. Ample time is allowed for these particles to rise into the slag, an important part of the procedure.

The slag is not allowed to become too acidic, since it would then be too viscous to extract the oxide particles. Sufficient iron oxide is maintained in the slag to prevent the metal from becoming over-reduced and sluggish due to liberation from the slag of silicon which reacts with iron oxide in the metal to form suspended particles of silica. Any tendency towards sluggishness, as shown by spoon samples, would render the metal altogether unsuitable for intricate castings and is corrected by the addition of iron ore or scale.

Deoxidising.—The gently-boiling bath is stilled by adding high-carbon low-silicon pig iron which eliminates most of the iron oxide from the metal without forming non-metallics. The required amounts of any ferro-alloys are added and deoxidation is completed by adding ferro-silicon and ferro-manganese. The metal being of the desired composition, at a suitably high temperature and fully deoxidised, it is tapped into the ladle, care being taken to keep the slag level above the tapping hole.

(To be continued)

Iron and Steel Prices

The Minister of Supply has made the Control of Iron and Steel (No. 72) Order, 1949, which came into operation on June 28th. It increases the maximum prices of Spiegeleisen and of rainwater and soil goods. Copies of the Order may be obtained from H.M. Stationery Office, or through any bookseller.

Phosphate Processes for Iron and Steel

with Special Reference to Rust-proofing

By E. E. Halls

Initially developed to protect iron and steel against corrosion, and still principally used for that purpose, the results of research work with the phosphate processes have greatly increased the scope of their usefulness. In recent years, phosphate treatments have been developed for imparting wear resistance in numerous cases in which metal to metal contact is involved in the functioning of a mechanism. In some instances sheet or strip is phosphatised to assist drawing operations in pressing and to reduce wear on tools. These applications are reviewed and some test results are given.

SINCE the appearance over forty years ago of the Coslett patents for the rust-proofing of iron and steel in phosphoric acid containing solutions, much progress has been made towards perfecting industrial phosphatisation processes. The early processes were not very reliable; they were uncontrollable and relatively expensive in operation, and they yielded variable results, which often failed to approach the quality expected of them. Their limitations were largely due to a lack of understanding of the complex reactions concerned and in some measure to the restricted state of development of plant and processing techniques. It is probably still quite true to state that our knowledge of the reactions concerned, those in the solution and at the base metal surface, in both the chemical and metallographic senses, is far from complete. On the other hand, so much research has been conducted in this direction by the specialists sponsoring various proprietary phosphate processes, that sound and rapid industrial progress has been made. This state of affairs has enabled a rational choice of process and processing conditions to be made to suit the metal and/or type of article, to be treated, and, what is perhaps most important of all, has provided accurate procedures of process control from which to assure that predetermined quality results are uniformly attained.

Modern phosphate treatments for iron and steel are precise and controllable processes of which there are several types from which to choose the most appropriate for the nature of the metal to be treated, its composition (plain carbon or alloy steel, etc.), its form (sheet, strip, casting, pressing, etc.), and its condition with respect to surface and contamination. When a miscellany of work has to be handled, a sound compromise can be made to suit the variety of components involved. Again, some treatments that are suitable for the ferrous metals are also applicable to zinc and zinc alloys, and to aluminium and aluminium alloys, so that if the flow of work includes these materials in quantities insufficient to justify the installation of separate chemical pretreatment processes for them, processes that are universally applicable can be adopted. This is particularly convenient if a fabricated assembly embodies steel and zinc, steel and aluminium, or steel, zinc and aluminium alloys, because a single processing becomes a practicable proposition.

These improvements in phosphatisation processes have been attended by a transition from the simple Coslett type of solution for the purpose to the present relatively complex formulations, some of which are patented and some are proprietary secrets. The original "phosphoric acid solution saturated with ferrous sulphate," has been thus transformed into mixtures containing compounds of manganese, copper or zinc, or nitrates, as accelerators. At the same time processing times of several hours have been reduced to periods ranging from a minute to about half an hour. Operating temperature too has been improved, about 185° F. being usually the closest approach to the original boiling conditions, while some processes operate lower and even at room temperature.

The principal use of the phosphate processes is for "rust-proofing," namely, the protection of iron and steel against corrosion. They are generally applied to components, but in some cases, stock is treated. Particularly in Germany, phosphatised and lacquered steel sheets were extensively employed as a substitute or replacement for tinned sheet, and such material was largely used in "tin" box and can making. In recent years, phosphate treatments have been specifically developed for imparting wear resistance—e.g., pistons, cylinders, gears, and in numerous instances in which metal to metal contact is involved in the functioning of a mechanism. A closely similar application concerns pressing and deep drawing, for which the sheet or strip material is phosphatised, to assist the drawing operation. By this means, the wear on tools is lessened and their service life increased, and moreover it may be possible to draw a deep pressing in fewer operations or to use a quality of material which, without phosphatising, would fracture.

Rust-Proofing

In the rust-proofing field, phosphate coatings in themselves are not usually very rust-resistant; it is a combination of the phosphate coating with a subsequently applied organic finish that fulfils the role of corrosion resistance. This additional medium may be oil, wax, paint, enamel, varnish, lacquer, or kindred material, and the improvement of the protective value of the organic medium by the presence of the phosphate layer is out of all proportion to the cost of applying it.

The phosphate process is applied to the material or component in a suitably cleaned condition; the excess of phosphatising chemicals are removed by water rinsing, and then the work is given a rinse in water containing a very small proportion of chromic acid, which is not washed off but allowed to dry into the coating. This is an important step in the process because it materially augments the protective value that the phosphate coating confers upon the metal.

The phosphate coating is not merely on the surface of the metal; the process is a conversion action, whereby the surface of the metal becomes converted to metal phosphate which penetrates uniformly into the surface to a depth dependent upon the particular process (and therefore chemical formulation) utilised and the time and temperature of treatment. Consequently, the phosphate coating is intimately bonded to the base material from which it cannot be removed by bending or flexing but only by abrasive means. Further, it is crystalline and porous, and therefore presents absorbent properties to the organic medium applied to it. It is for this reason that it provides a very good basis for the adhesion of paints, enamels, lacquers and varnishes. The same property enables it to be "impregnated" with wax or oil, and coloured wax or oil. The role of phosphate coatings in producing wear-resisting surfaces, and in being favourable for deep-drawing operations, is likewise explained because the nature of the coating enables the lubricant to be held as well as preventing metal to metal contact.

In most chemical and electrochemical treatments, it is important to ensure that all traces of the chemicals used in the solution or electrolyte are removed by thorough water washing operations, and work for treatment must be designed with a view to this. Thus, any features of the design that favour the trapping of chemicals have to be avoided. These unfavourable aspects include folds and seams, overlaps, blind-holes and similar interstices. It is almost impossible to wash them free from the chemicals that enter them and in consequence corrosion occurs within, or around the area, as the chemicals gradually seep out during service. By contrast, the phosphate chemicals are not objectionable in this manner, and if work is oven dried at the end of the sequence of operations, there is virtually only the effect of excessive phosphatising in the junction holding the chemicals. If dried from hot water there may be a slight superficial stain around the area of the interstice but this is not harmful. It is, therefore, important to note that components assembled by spot welding, bolting or riveting, that containers having folded seams, and articles having such overlaps or interstices, can be safely phosphatised without fear of added corrosion troubles at the interstices, a practice that in electroplating, chemical colouring and similar treatments, gives serious troubles.

Although the phosphate coatings on iron and steel are not in themselves rust-proof, they possess corrosion inhibitive qualities to such a degree that they retard the development of rust, as well as preventing or delaying its spread. On steel surfaces without this chemical pretreatment, moisture penetrating the organic finish coating weakens the adhesion, causes corrosion beneath the coating and assists in accelerating the deterioration of the organic film. Again, at points of damage or rupture in the latter, rapid rusting occurs and spreads beneath the film. With phosphatised surfaces, rusting beneath the film is inhibited, and although rusting occurs at points of rupture, it does not spread unchecked beneath the film. The phosphate coating thus has the properties of the inhibitive pigment in primers—e.g., red lead, red oxide of iron, yellow zinc chromate, etc., and, by virtue of its mode of formation firmly attached to the iron, it is more effective.

Often assemblies for treatment may include other metals such as nickel silver, brass, bronze, copper and tinned or soldered parts. Phosphatising is without effect upon these; hence, brass and copper eyletting or riveting, the assembly of nickel silver springs, and the spot-welding of tinned lugs from which subsequently to take soldered connections, is permissible before treatment.

Some of the advantages of phosphatising as a preliminary to the application of organic protective coatings for the corrosion prevention of iron and steel can be summarised as follows:—

(*a*) Simplicity of processing using conventional types of plant and involving simplest of orthodox precleaning methods.
(*b*) Responsive to simple inexpensive control methods.
(*c*) Rapidity of operating, signifying minimum of plant, floor space and overheads.
(*d*) Applicable to wide range of irons and steels in all forms of numerous assemblages, in which interstices such as those provided by seams, overlaps, etc., are not objectionable.
(*e*) Process not interfered with by many other metals such as coppers and copper alloys, nickel and nickel alloys, solders, etc.
(*f*) Phosphated coating assures adhesion, and retention of adhesion, of coatings of enamel, etc.
(*g*) Normal ageing propensities of enamels, etc., are retarded or eliminated.
(*h*) In conjunction with organic finish, provides a reliable rust preventive and corrosion-resisting finish.
(*i*) Creep of rust from mechanically damaged areas of finish greatly retarded or eliminated.
(*k*) Better adhesion and improved ageing properties of the coating of enamel, etc., yields better serviceability with greater wear resistance, greater flexibility and shock resistance, and better durability under arduous severe conditions involving mechanical damage.
(*l*) Need for a special inhibitive primer generally eliminated.
(*m*) Generally a saving of at least one coat of paint but coupled with this, superiority in all round serviceability including corrodibility and mechchanical aspects.
(*n*) Reasonable cost so that initial cost of finishing is actually lessened rather than increased, and overall cost is greatly reduced by elimination of preliminary failures and by less frequent refinishing in service.

Although phosphatising has enjoyed these advantages for a considerable number of years, it will have been noted that this has not prevented rapid advances during this same period, nor does it mean that there is little yet to be done. One feature in particular demands, and is receiving attention; this concerns grain size of the coating. Coarse heavy coatings may absorb the organic finish very readily, and if the medium is a thin material of pale shade, several coats may be required to secure uniformity. The answer to this is a lighter phosphate layer of smooth texture. More work requires to be done in this direction including not only the controlled production of phosphate coatings with special reference to the physical condition of grain size and orientation, but also the performance of various types of coating with respect to the serviceability of the combined

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The Glasgow Herald. January 27, 1949

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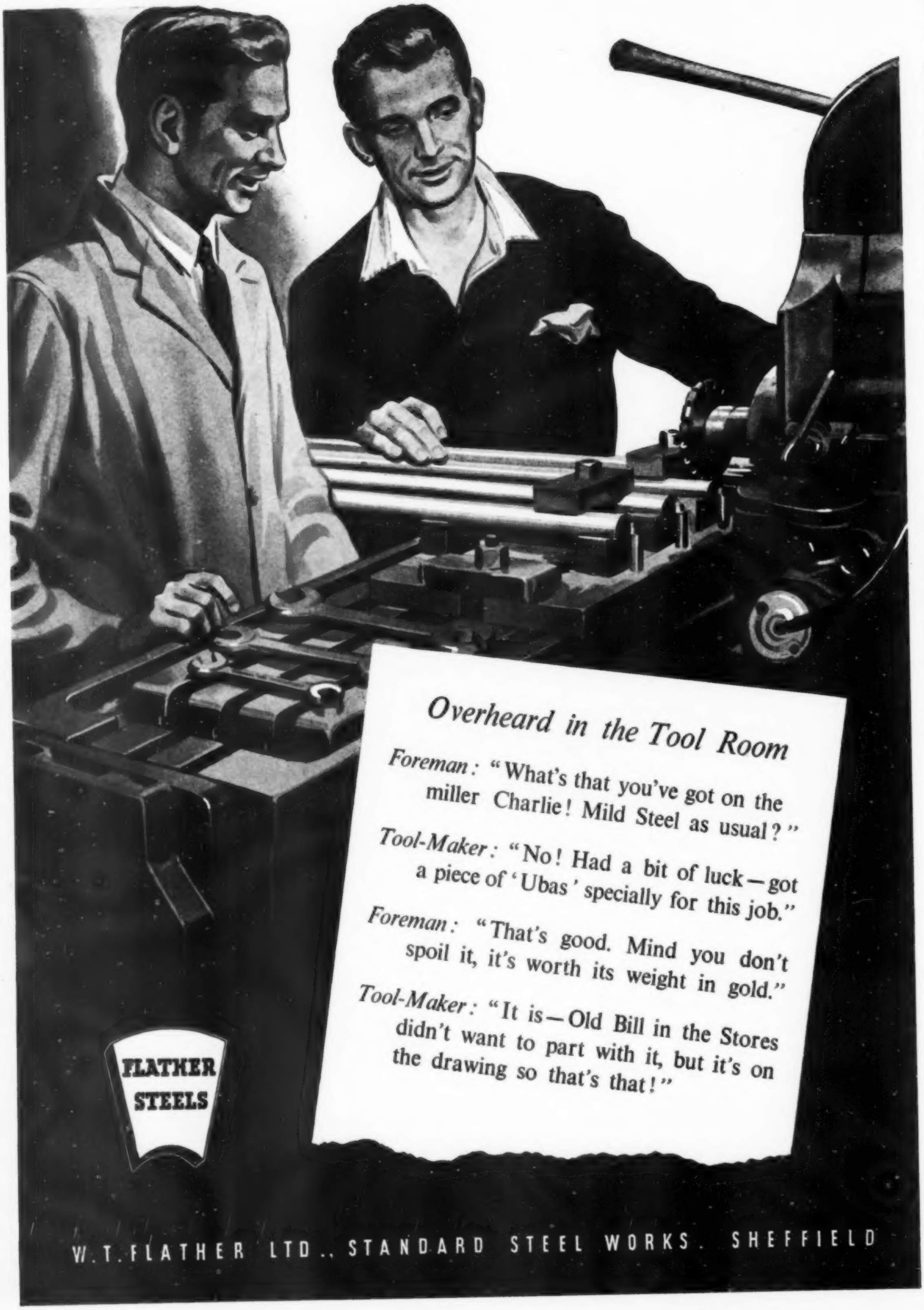

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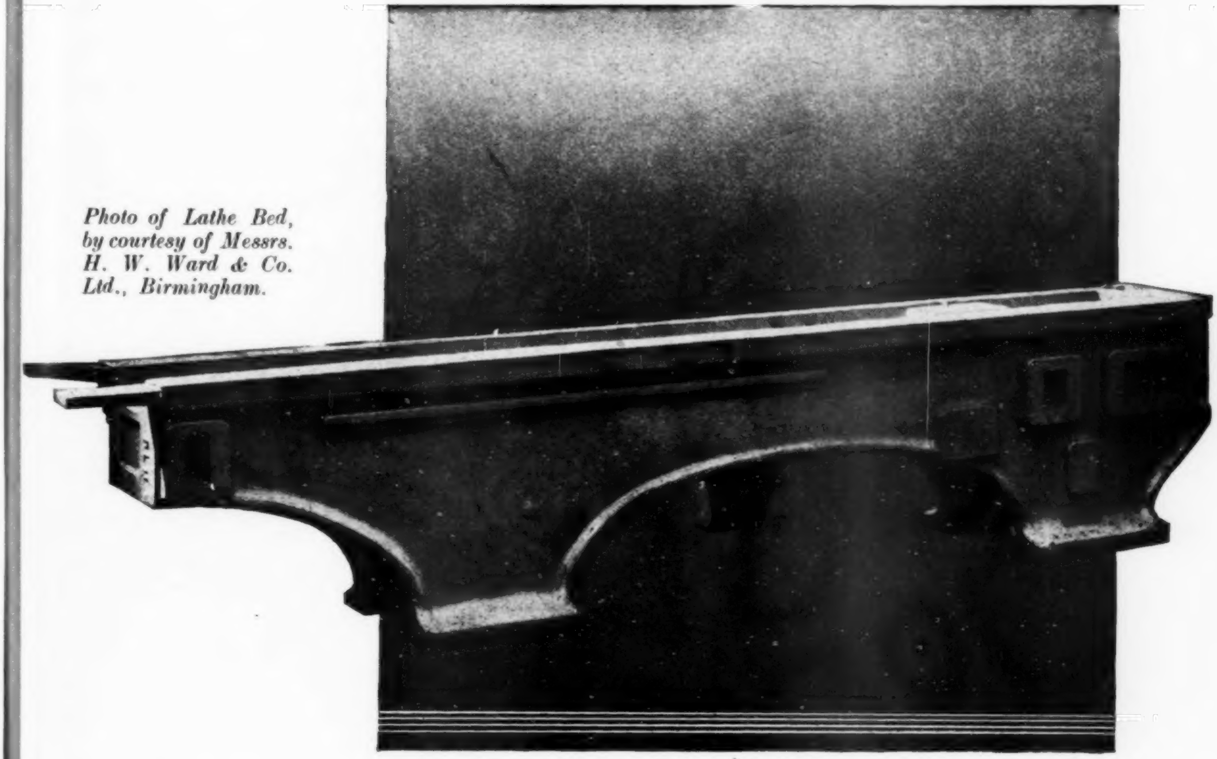

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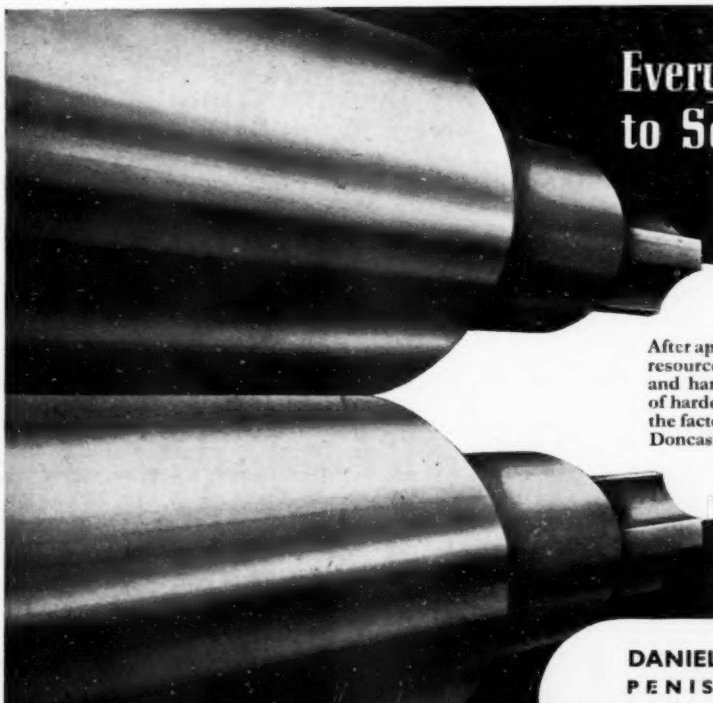

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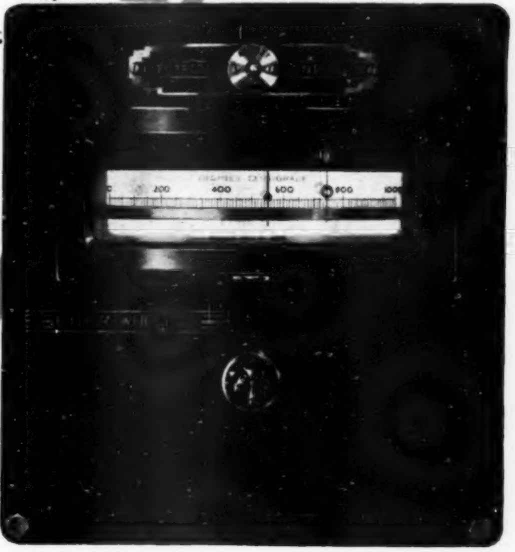

Fig. 1.
Ether-Wheelco "Capacitrol" Automatic Temperature Controller.

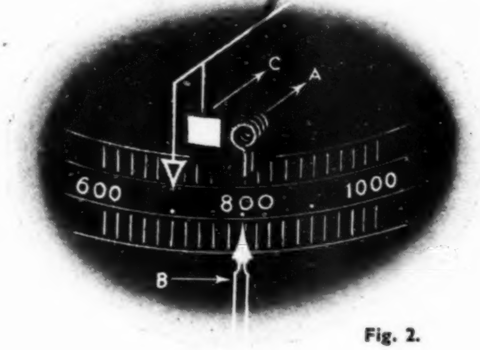

Fig. 2.

Fig. 2 shows the way in which the science of electronics is used to automatically control temperatures, with the speed of light, great accuracy and no interference with the measuring system. A light aluminium flag "C" passes between two coils "A" of the electronic system, when the flag enters the sphere of influence of the coils a movement of a few thousandths of an inch is sufficient to switch the control system off and on. By moving the coils attached to the pointer "B" the control position can be readily adjusted.

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phosphate/organic finish. It is felt that more information upon optimum values will have a favourable reflection upon economics.

There is no record of any medium (paint, enamel, lacquer or varnish) for which phosphate coatings have proved unfavourable, and in fact the general conclusion is that lower-grade enamels, etc., which may be quite unsuitable when applied directly to the (properly cleaned) metal work, give quite good performance with phosphate pretreatment. Nevertheless, when technicians spend the effort of designing finishes, they usually consider it soundest to select the best available organic media—i.e., those that provide the most favourable durability cost ratio.

In studying finishing materials to this end, it is found useful to study them on plain steel and on phosphatised steel because, with two media of apparently equal merit, the same degree of improvement by phosphatising is not always secured. It is, therefore, considered that some fundamental work is required upon the influence of the phosphate coating upon organic coatings of various types. With the widely varying classes of "synthetics" now employed—viz., cellulose, vinyls, alkyds, phenolics, ureas, melamines, etc., anomalies are bound to arise sooner or later, and national economics emphasize the necessity of making the soundest selection.

Phosphatising Operations

To appreciate fully all that is entailed in the process of phosphatising, details of the operations will now be discussed.

Work for treatment must be clean, a requirement which is common to all finishing treatments. Cleanliness signifies freedom from all foreign matter, but there may be certain reservations in some cases. All oil and grease must be removed, and so must loose dirt, and often one operation will take care of both types of contamination. A "turps wipe" is commonly specified, and this signifies a manual operation of wiping over the surfaces of the work with a cloth soaked in American turpentine, turps substitute, white spirit, solvent naphtha, cheap grade lacquer thinners, or similar material. Heavily contaminated work requires two such wipes, the first to remove the bulk of the foreign matter and the second as a final clean. Such a procedure is one of the most satisfactory preparatory treatments for phosphatising, and there is often no simple alternative when dealing with cabinets, frameworks and other large structures, panels, boxes, etc. Smaller components can be given an equivalent immersion treatment by rinsing in the liquid solvent, with the aid of a brush where useful. Here again two treatments are given, the first in "spent" solvent, the second in "clean" solvent; sometimes paraffin oil is used as the first solvent, and this is a remarkably good cleaner for the purpose. Another type of process uses the conventional trichlorethylene degreasing plant, but a liquor-vapour degreaser is preferred, because vapour alone will not remove solid dirt, dust and swarf.

If the grease contamination includes soap base products, such as heavy soap type press lubricants, the solvent cleans will not be entirely satisfactory unless brushing in paraffin oil is included. In such cases, aqueous alkali cleaning must be used; such cleanses can remove all the above types of foreign matter. For heavy contamination, two treatments are advocated, the first using a heavy duty alkaline cleaner, having a caustic soda base, and the second employing a light-duty one, having a sodium metasilicate/carbonate base or similar composition; water washing after each is necessary. When alkali cleanses are used, however, every precaution must be taken to see that no alkali is carried over into the phosphatising solution, otherwise some of the acidity in the latter is neutralised and the balance of the solution is upset. This point is particularly stressed because the fault can so easily occur, and proper phosphatising becomes impossible. Not only can cupped work easily carry over solution from a previous immersion operation, but alkali will certainly be retained in blind holes, overlaps and seams. This type of treatment should be avoided on such work, and this can usually be arranged quite simply by controlling the use of the machine lubricants in the fabrication of the components.

For the bulk of work to-day, the solvent or alkali cleanse is the only pretreatment required, because the majority of fabricated parts are made of "clean" steel of the deep-drawing, bright mild, furniture, motor car body, full silver, or semi-silver types. Work that has been allowed to rust, and that produced from black sheet such as C.R.C.A., and from black iron and structural steel section will need consideration with respect to rust and scale. The same efficiency of phosphatising over such contamination cannot be expected as on material from which it has been removed.

Phosphate solutions are acidic and will "pickle" off rust simultaneously with phosphatising. However, they are not intended to fulfil this role, they are an expensive form of pickling, their balance may become upset, and the rusty areas are coarse and rough in contrast with the remainder of the surfaces. Traces of rust may be neglected or removed locally with a wire brush or other abrasive means. Heavy or general rusting must be removed by acid pickling in phosphoric, hydrochloric or sulphuric acid base solutions, or by abrasive blasting with sand or crushed steel grit. If pickling is employed, thorough water washing must follow to ensure that acid is not carried over into the phosphate solution. For work with seams (soldered, folded, or spot welded), the pickling should be applied at a convenient stage prior to "seaming" in order to avoid any retention of acid in the folds.

It should be borne in mind that rusting causes damage to the surface finish of material and that the phosphatising will follow the surface irregularities and that there will be a different degree of absorption of the organic medium finally applied. Uniformity of finish is, therefore, impossible in a single coat of paint or enamel and several coats or considerable surfacing may be necessitated. Consequently, for work in which ultimate appearance is of primary importance, it is essential that raw material and component parts should be properly protected and stored, and not allowed to rust.

When mill scale is in question, such as that associated with black steel bar and section, and structural steel work in general, the most satisfactory treatment after degreasing is by shot or sand blasting. The abrasive must be of suitable mesh size and of good cutting quality, and the process properly controlled. Under these conditions, a uniform finish with the scale completely removed and not merely burnished can be obtained. The best stage at which to abrasive blast is with the material in length prior to fabrication and assembly.

When abrasive blasting plant is not available, pickling may be employed. Often, however, wire brushing only is used. This is satisfactory provided that all loose scale is removed, but it is always questionable how far this is practicable. It is true that a phosphate film forms to some extent on top of the scale, and that this film does give quite satisfactory adhesion to the organic coatings and that it provides a really good measure of protection. The principal weakness rests with those areas of scale that are not properly adherent and which become detached at a later date.

The cleaned work is ready for the phosphatising operation proper, to which it is passed in the dry condition if solvent cleaning only, or solvent cleaning plus abrasive blast, were the preparatory operations, or wet from the water washes after alkaline cleaning or acid pickling. In the phosphatising process, all the work surfaces have to be exposed to the aqueous solution containing the phosphatising chemicals for a precise time period at a controlled temperature. The work may be treated by immersion, or by spray application of the solution ; brush methods for specific purposes have also been developed.

The most usual phosphatising processes use immersion methods with the temperature of the solution controlled thermostatically to 180°/185° F. Immersion times for work of good surface condition range from 2–5 minutes ; for rougher surfaces, including those that are black or scaly, the time is extended to 10–15 minutes. Heavier phosphate coatings can be acquired by increasing the time period to say 30 or 40 minutes. The shorter times are satisfactory as a preparation for paint and enamel, but the longer time is preferred if the work is to be waxed or oiled and stained.

The phosphate solution is prepared from proprietary chemicals to the suppliers instructions with respect to concentration, and the acidity is maintained at a constant level by periodic additions of make-up chemicals as shown to be necessary by simple analytical control tests. Lower temperature operating solutions have more recently been developed, and they will gradually be introduced in new installations or by changing the chemicals in existing plants. Much work has been done on cold phosphatising ,and processes employed in production in, for example, Germany. Such methods are most useful for very large structures, too large for convenient immersion, and for the treatment of part areas. They may too be useful in the finishing of equipment already erected, or in its refinishing. All these processes are based on the same principle of intimate contact between the work surfaces and the solution for a controlled time period of several minutes, and then rinsing away excess solution.

The treated work is next rinsed in hot water without over-washing. The chemicals are quite free rinsing, and it is advisable to avoid too long a washing period with " hard " water which is alkaline due to the lime it contains. Next a hot chromate rinse is given, giving about 30 secs. immersion at 175°/185° F., using a solution of 0·5 lb. of chromic acid per 100 gals. of water ; excessively hard water may require a little more acid addition. Analytical control can determine the rate of flow of water into the rinse tank to avoid it becoming excessively contaminated, and the time period of replenishment for the chromate rinse. After the latter, heavy work can be allowed to dry off from its own retained heat, but it is preferable to over dry lighter work. In fact, it is advantageous to oven dry all phosphatised work, especially that having seams. The treated work has a dark greyish appearance, and the presence and intensity of the coating can be visually seen by drawing the back of the thumb nail lightly across the surface. If work is allowed to stand in the wet condition, a brownish film may develop, and a brownish stain may form from seams. These imperfections are not objectionable from the rust-proofing angle, but they spoil the appearance of the work, and, if oven drying is catered for, they indicate a lack of efficiency in the execution of the work.

In the immersion processes, automatic or semi-automatic operating is advantageous in providing control of the time cycle, and in ensuring that the maximum is obtained from the plant capacity. The oven drying can form part of the line of operations so that for a predetermined time of passage through the oven, the heat of the latter can be adjusted and controlled to assure full drying. An oven temperature from 250°–500° F. can be safely employed except when a portion of the work contains soldered or tinned items, in which case 250° F. should be the maximum value.

In the spray methods, work is precleaned as already described, but the " spray line " includes a weak alkaline spray at its commencement. This assists in wetting the work as well as in the removal of final traces of grease and dust. Thus the spray line comprises a series of chambers for bombarding the work from judiciously arranged sprays with the alkali, the phosphate and the chromate solutions, and with water washes interposed between them, and after the last. Drain-boards run the excess liquors that drain off the work back into the correct compartments, and baffle plates also assist in preventing contamination entering from one section to the next. The solutions are continuously pumped to the spray heads, and are controlled and maintained in the sumps. Temperatures are of the order of 185° F. and the time of treatment which is about 1 minute in the phosphate zone, is controlled by the rate of travel of the conveyer. The final drying zone is incorporated in the same line.

Spray phosphatising is a very fine way of operating the process because it gives precise control of all the variables. Work has to be of the same or similar type, and consequently the method is usually restricted to the mass production of a single component, or a few components, but it could be applied economically to light work of miscellaneous type provided that such work is restricted within upper and lower limits of dimension.

Small work such as screws, nuts and bolts, can be treated by barrel methods, which conform to the same primary rules.

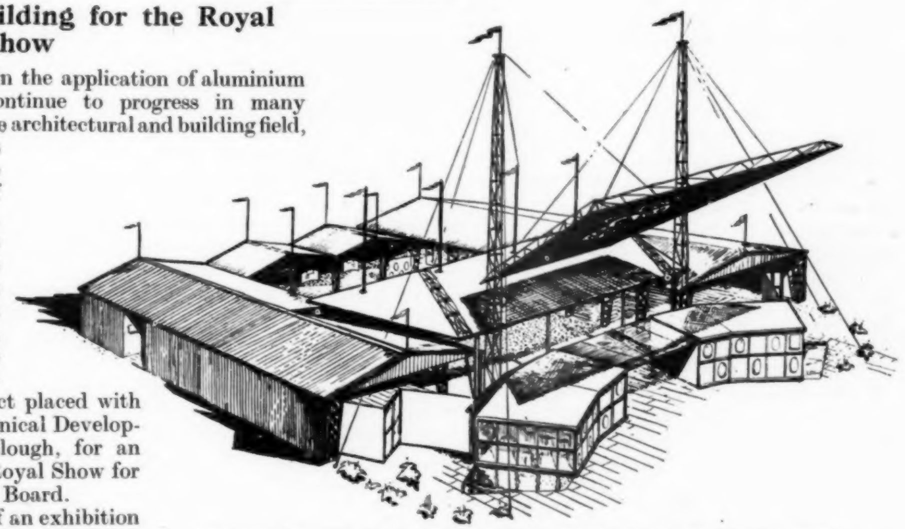
Some steels exhibit patches or large areas that are very difficult or impossible to phosphatise by the general methods described. After treatment the unaffected areas show an almost silvery whiteness and a hydrochloric acid pickle is necessary to make these areas respond to the process. Sometimes a cathodic alkaline clean is additionally necessary. The explanation of the shortcoming is probably the rolling-in of grease during the manufacture of the sheet. Another trouble often experienced is slow response to the phosphate solution exhibited by material or components that have been " lying around " for some time. The reason for this is obscure, but it is partly accounted for by the decomposition of the rust protecting oil coating to a soapy film which is difficult to remove by means of solvent only, and partly by the accumulation of dirt and smut which probably assists in the formation of this refractory film. The procedure for overcoming this difficulty is not a simple one, and it entails hot electrolytic alkaline degreasing with the work as cathode, and a cathode current density over all work surfaces of at least 10 amps./sq. ft. The hydrogen evolution from this assists in forcing the contamination from the work surfaces. Sometimes a subsequent acid pickle is also beneficial.

These shortcomings can in the main be avoided, firstly by inspecting the raw material when received for freedom from poor areas, secondly, by ensuring that a high-grade rust preventive is employed upon the material, and thirdly, by providing proper storage for material and components so that undue dust from concrete floors soot, etc., does not collect upon them.

Broadly speaking, any of the industrial finishing media may be used upon phosphatised surfaces with advantage from the phosphate treatment in the directions already enumerated. Air drying cellulose lacquers and enamels, air drying and stoving oil base media, and air drying and stoving " synthetics " of the alkyd, oil modified alkyd, urea/alkyd, and oil modified phenolic resin types have all been successfully employed. All materials do not give the same degree of benefit, and the same type of medium from different manufacturers, will perhaps yield differing qualities of performance. It is always possible that the constituents in the phosphate coating may influence organic film in the direction of accelerating or retarding polymerisation, although to date no positive data have been collected on this phenomenon. Consequently, the performance of the organic medium should not be taken for granted, but the same rational mode of selection should be made as is the case for the finishing of any other base material.

Some test results will be given in the concluding part together with a reference to phosphatised sheet as a substitute for tin-plate and a discussion on phosphate coatings for wear resistance.

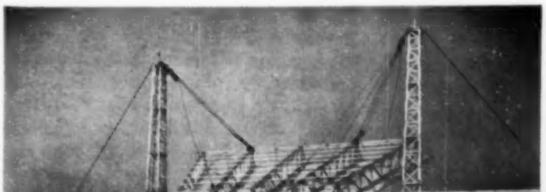
Aluminium Building for the Royal Show



Midland Electricity Board's exhibition stand at the Royal Show.

DEVELOPMENTS in the application of aluminium and its alloys continue to progress in many fields, notably in the architectural and building field, indeed it is probable that to-day this provides the largest single avenue of aluminium consumption. Recent years have seen considerable progress in the use of aluminium buildings, many of which have been standardised, and an indication of the popularity of these buildings is the recent contract placed with the Structural and Mechanical Development Engineers Ltd., Slough, for an exhibition stand at the Royal Show for the Midland Electricity Board.

The contract consists of an exhibition stand approximately 120 ft. wide by 110 ft. long overall, for which an aluminium alloy structure was specified in view of the ease of handling and erection whenever the stand is to be used. Although the stand will be used in its entirety for the Royal Agricultural Show 1949, it may in the future be used either as a whole or in various parts. The main exhibits will be housed in two Alframe buildings, Mark III type, each 81 ft. long, with a communicating portion between them at the rear of the stand. The buildings are only partially enclosed, and have therefore been provided with portal bracing frames in order to give the necessary longitudinal stability which is normally provided by the wall panels. The roofs of both Alframe buildings and the connecting portion at the rear are covered with aluminium alloy corrugated sheets, as also is the whole of the rear wall. In addition, there is an administration block at the front of the stand, for which an aluminium alloy structure is used which is to be clad both internally and externally to form office accommodation and also to carry suitable decoration.



Showing two 50-ft. towers supporting the main canopy and structural parts of the building.

The main feature of the stand is two canopies carrying advertisement slogans, the lower one which is approximately 66 ft. wide by 32 ft. long, being supported at the front and rear on eight tubular columns in all. The upper canopy is approximately 52 ft. wide by 42 ft. long, and is suspended in mid air in a sloping position, the front being 34 ft. above ground level, and the rear 19 ft. above ground level, suspended from two pylons each 51 ft. 3 in. above ground level to the top of the flag pole. The pylons and the whole of the structure for both canopies are of aluminium alloy, the lower canopy being covered with corrugated aluminium alloy sheet and the upper canopy with aluminium alloy expanded metal.

The total weight of aluminium in the structure and sheet metal covering is approximately 14 tons.

The Corrosion of Metals

At a recent meeting of the London and South Eastern Counties Section of the Royal Institute of Chemistry held at Medway Technical College, Gillingham, with Dr. J. G. A. Griffiths in the chair, Dr. F. Wormwell, of the D.S.I.R. Chemical Research Laboratory, Teddington, presented a paper on the above subject, illustrated by lantern slides and specimens.

In his opening remarks, Dr. Wormwell emphasised the fact that the corrosion of metals represented a "return to nature" in the sense that it involves the recombination of the metal with oxygen and other elements, yielding corrosion products that are similar in composition and structure to compounds occurring in nature as ores. The corrosion process proceeds spontaneously, since it is accompanied by a decrease in free energy. As distinct from direct oxidation of the metal, e.g., the formation of scales on heated metal, corrosion is usually the result of chemical or electro-chemical processes, the end-products of which are oxides or salts of the parent metal. He then proceeded to discuss briefly the factors controlling corrosion rates in conditions of atmospheric exposure, immersion under water and burial in the ground. The main part of his lecture dealing in greater detail with corrosion in immersed conditions, particularly in neutral waters, in salt solutions and in sea water.

A study of the mechanism of corrosion leads naturally to a scientific approach to methods of protection. These may be grouped as follows :—

(1) Modification of the metal, e.g., removal of impurities, or alternatively, alloying with other metals.
(2) Suitable choice of metal in relation to the environment in which it is to be used.
(3) Modification of the environment. This may take the form of de-aeration or chemical treatment to remove corrosive constituents ; alternatively, corrosion inhibitors may be added to the water.
(4) Cathodic protection, using "sacrificial" anodes, with or without applied E.M.F.
(5) Protective coatings, consisting of (*a*) suitably resistant metal ; (*b*) non-metallic coatings such as oxides or other surface-conversion coatings ; (*c*) organic coatings of the paint or enamel type.

The study of the mechanism of corrosion and of methods of protection were illustrated mainly from the work of the D.S.I.R. Corrosion Research Group at Chemical Research Laboratory, Teddington, under the leadership of the late Dr. G. D. Bengough and of Dr. W. H. J. Vernon. The techniques employed in these investigations have included accurate measurements of oxygen absorption and hydrogen evolution, the use of elevated pressures, low-speed and high-speed rotor apparatus, supplemented more recently by measurements of electrode potential, resistance and capacitance of painted metals. The emphasis throughout has been on quantitative measurements in strictly defined conditions. The work of the Teddington Group has contributed, along with the researches at other centres in this country and abroad, to the fuller understanding of corrosion processes and to the development of improved methods of corrosion control.

Discussion

Dr. Griffiths opened the discussion by asking Dr. Wormwell to elaborate on the iodine-absolute methanol reagent used in stripping protective oxide films on steel. Dr. Wormwell explained that the iodine attacked the metal just below the film and this reagent was preferable to U. R. Evans' iodine-aqueous potassium iodide reagent since absence of water and air was necessary to avoid possible oxide formation.

Major P. A. Cartwright, who observed that chemical corrosion is often as important industrially as atmospheric corrosion, asked if the lecturer could clarify the confusion due to the different methods of assessing corrosion rates appearing in publications, referred to the lecturer's omission of cementation processes amongst protective coating treatments, and questioned whether anodised films on aluminium were self-healing. Dr. Wormwell agreed about the importance of chemical corrosion and cementation processes, outlined one C.R.L. method of assessing corrosion rates by skimming off surface metal until no corrosion pits remain, and recording the thickness skimmed off as the maximum depth of corrosion, and explained that he claimed self-healing properties only for natural and not for artificial anodised films.

Mr. R. Buckley asked the lecturer why metals corroded rapidly in the vapour phase but not in the liquid phase of a mixture of sulphur, lime and water heated under pressure ; also whether corrosion of tin-plate containers, with consequent change to contents, is due to pinholes and if so, whether by galvanic action. Dr. Wormwell pointed out that the sulphide mixture would be obviously very corrosive in the vapour, but not in the liquid because of exclusion of oxygen ; tin-plate is liable to have mechanical pinholes, which permit galvanic corrosive action between tin and iron.

In reply to Mr. H. E. Monk, Dr. Wormwell said that failure of water mains due to corrosion by sulphate-reducing bacteria or galvanic action could be diagnosed usually by the graphitisation of the pipes due to sulphates in clay soils and sulphide may often be detected in, and vibro desulphuricans isolated from, fresh soil samples ; most clay soils contain sufficient sulphate to cause corrosion if other conditions are favourable.

The lecturer agreed with the suggestions from Mr. S. V. Sergeant that aliphatic acids might be as satisfactory as succinic and cinnamic acid derivatives as vapour phase corrosion inhibitors, and that stoved phenol-formaldehyde might be a satisfactory substitute for lead lining to protect against 10% sulphuric acid, but he had no information as to the relative costs of painting and cathodic protection or the relative efficiency of lead-cladding and lead-lining in preventing edge attack of steel by creepage of acid.

Induction Brazing Methods Applied to Permanent Magnets

By D. Hadfield

Magnetic Research Laboratory, Wm. Jessop & Sons, Ltd., Sheffield

Difficulties previously encountered in the fabrication of permanent magnets, involving the use of the newer magnet materials, have been overcome by the adoption of the induction brazing methods described. The process has freed the high energy anisoropic magnet alloys for a wide range of instrument uses.

THE introduction of the modern permanent magnet alloys has resulted in the magnet manufacturers seeking alternative methods of production owing to the difficulties which arise on account of the peculiar mechanical properties and extreme hardness of these Al-Ni-Co-Cu-Fe type alloys. Whereas steel permanent magnets can be machined, drilled and tapped prior to hardening and used as a "chassis" for an instrument assembly, the newer permanent magnet materials of the last decade have necessitated special clamping arrangements being devised to secure the magnet alloy part. This applies to the isotropic Alnico alloys and high energy anisotropic Alcomax and Hycomax alloys. Recently, due to the application of the induction brazing technique to permanent magnet fabrication, neater and more attractive designs (Fig. 1) from the user aspect are now available, which are economic, and with which this account is concerned.

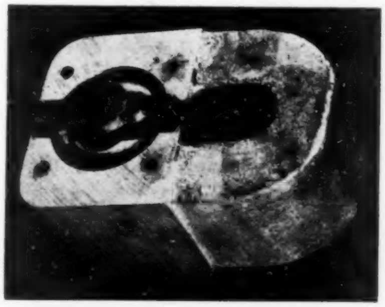


Fig. 1.—Typical brazed magnet.

The Induction Brazing Process

The induction brazing process permits of a pre-machined soft-iron blank being rigidly brazed to the ground face of the permanent magnet part without excessive local heating. In the Magnet Department of Wm. Jessop & Sons, Ltd., Sheffield, the heating energy is supplied from 10-kw., 5,000 cycles per second, motor-generator induction heating equipment, using a close-fitting single-turn hollow water-cooled copper coil surrounding the joints between the respective materials, as shown in Fig. 2. Before applying the heating, a "sandwich" is made of dry aluminium-bronze borax flux, melting at 500° C., and a piece of silver-solder strip 0·008/0·010 in. in thickness, and of area equal to the cross-sectional area of the parts being joined. The silver-solder melts at 605°/625° C. The magnet part is supported with its limbs vertical and the other component rests on top of it with the brazing materials between the joined surfaces. The selection of the flux used is very important as there is a wide composition difference between the materials being brazed. The magnet alloy part contains about 9% of aluminium, and to obtain a sound mechanical joint, the formation of aluminium oxide must be avoided. The borax-base aluminium-bronze flux adequately fulfils this requirement.

The high-frequency current is passed through the coil for the minimum possible time sufficient to heat up the silver-solder and the joining faces until the flux and silver-solder are fluid, and then a slight pressure is applied to the topmost part while the braze is solidifying, as shown in Fig. 3. In order to reduce the internal stress which may be set up during brazing, owing to the different coefficients of expansion of the magnet alloy and soft-iron it is advisable to allow the composite magnet to cool down in Kieselguhr. If necessary, the complete brazed unit may be tempered at say 500° C. for an hour or so, below the critical tempering temperature of the magnet alloy, in order to relieve the internal stresses, particularly where the ungapped soft-iron yoke forms a closed circuit, as in instrument magnets. The heating period will depend on the size of the magnet being silver-soldered. For a circular magnet, approximately 3 in. overall diameter and weighing about 1 lb., the period will be 10–15 seconds, while for a small magnet, of approximately 1 in. overall diameter and weighing about 2 oz., the period will be 5–10 seconds.

After silver-soldering, the excess material is removed by surface grinding or fettling, and, in the case of instrument magnets, the isthmus of soft-iron, where the pole tunnel has been drilled in the pole piece blank, is cut through by milling or by means of an abrasive slitting wheel in order to finish the machining of the magnet. Finally, the composite magnet is magnetised.

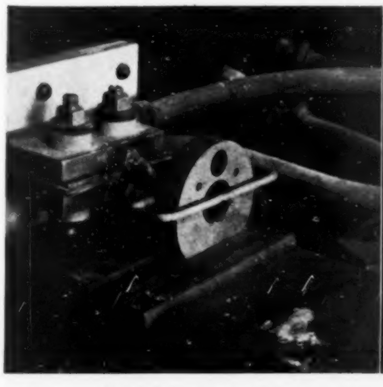


Fig. 2.—Induction brazing arrangement.

Fig. 3.—Brazing process.

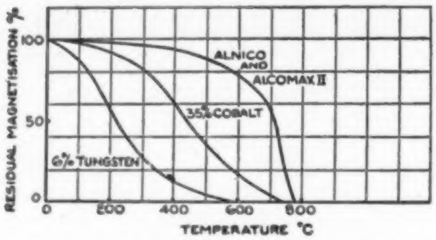


Fig. 4.—Effect of heat on magnetic properties.

Advantages

Heating of permanent magnet materials at increasingly higher temperatures has a detrimental effect on their magnetic properties, as indicated in Fig. 4, and from this it is obvious that furnace brazing at temperatures over 600° C. would cause the finished magnet to have an inferior performance. The advantage of the induction heating process is that it allows of controlled localized heating only where the joints are to be made and does not affect the condition of the already heat-treated permanent magnet part and annealed pole pieces. Its simplicity and speed offers economic advantages over other methods of assembly and its mechanical robustness has been established.

In the past, the use of the anisotropic Alcomax and Hycomax alloys has been somewhat restricted for some applications because, in order to develop their optimum magnetic properties, the material has to be heat-treated by controlled cooling from a high temperature in a constant unidirectional magnetic field having a form closely resembling that of the final magnetic circuit. This raised production difficulties where the magnetic path was of a circular nature but the difficulty was overcome by using a composite magnet whereby the permanent magnet component can be heat-treated without difficulty before attaching the soft-iron pole pieces necessary to complete the magnetic circuit. The two joints of non-magnetic material (only a few thousandths of an inch) have a very low reluctance compared with the reluctance of the air gap and do not materially affect the efficiency of such a composite magnet. Photomicrographs (× 10 and × 1,000) of a typical silver-soldered joint are given in Figs. 5 and 6. The soundness of the joint and the coarse crystalline structure of the permanent magnet material can be clearly seen.

Applications

The principal application lies in the manufacture of instrument magnets, a selection of which is shown in Fig. 7. Owing to the widely different magnetic and mechanical properties of the new alloys compared with the older steels, separate soft-iron pole pieces are now generally used and the pole tunnel is rarely formed in the permanent alloy itself on account of point to point variations of magnetic potential on the gap surfaces. The induction brazing process has thus freed the high energy anisotropic magnet alloys for a wide range of instrument uses.

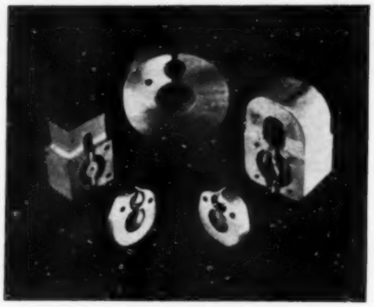


Fig. 7.—Selection of brazed composite instrument magnets.

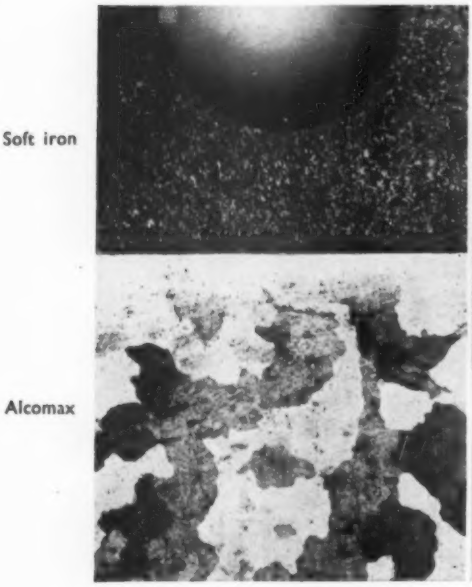


Fig. 5.—Brazed joint. × 10.

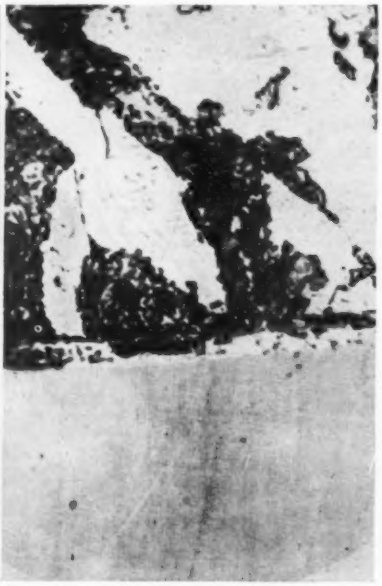


Fig. 6.—Brazed joint. × 1,000.

Other uses arise in the fabrication of permanent magnet stators for small D.C. motors, magnetos, and A.C. generators. Furthermore, in one modern type of watt-hour meter the disc damping magnet is now composed of a magnet alloy block and soft-iron yoke forming a double-gap magnet. These are only a few applications in which manufacture and assembly are simplified by localised induction brazing but many others will immediately spring to mind.

Using Ultrasonic Methods

The application of ultrasonic methods to the determination of the elastic constants of solids is considered in some detail by Schneider and Burton.* It is shown that a rotating-plate technique, in which ultrasonic transmission is plotted as a function of the angle of incidence of the waves, allows determination of the velocities of dilatation and shear waves in the plate. From these data, Poisson's ratio and the mechanical moduli may be determined. Details of an apparatus for making such measurements are given. The elastic constants of several metals have been measured with this equipment, and the values obtained are shown to be in agreement with previous published data. In addition, measurements of a number of thermoplastic and thermosetting resins have been made successfully. It has been found that in the case of Melmac Resin 26-8B there is no variation in the elastic constants as a function of cure time.

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* W. C. Schneider and C. J. Burton, *Jour. App. Phy.*, **20**, Jan. 1949, 48–58.

The Iron and Steel Institute

Summer Meeting in Norway

As part of the Summer Meeting of the Iron and Steel Institute, held in Norway, two technical sessions were held at which papers of mutual interest to British and Norwegian members were presented for discussion. Brief summaries of the papers presented are given.

Technical Sessions

ONE of the most important functions of the Iron and Steel Institute is the holding of meetings for the presentation and discussion of papers of technical interest. In the arrangements for the Institute's Summer Tour of Norway, this aspect was not overlooked, two technical sessions being held. The first was a joint meeting with the Norwegian Metallurgical Society and took place in the Aula of Oslo University, presided over by Sir Andrew McCance. Following a welcome by Dr. J. Görrissen, President of the Norwegian Society, and a response by Sir Andrew on behalf of the Institute, the following papers were presented and discussed: "Some Notes on Brittleness in Mild Steel," by J. Görrissen; "Experiences in the Study of Isothermal Transformations," by T. F. Russell and C. Mavrocordatos; "The Acceleration of the Rate of Isothermal Transformation of Austenite," by M. D. Jepson and F. C. Thompson; "Determination of an Isothermal Transformation Diagram with an Optical Dilatometer," by J. K. L. Andersen; and "The Properties of Olivine and its Use for Refractories and Moulding Sands," by K. J. Stenvik.

The second session was unique in the history of the Institute in that it was held on board ship at sea. The papers presented included "The Manufacture of Electric Steel in Great Britain," by the Electric Process Sub-Committee of the Steel Making Division of B.I.S.R.A. "The Söderberg Electrode System," by H. Christiansen, Junr., and B. Ydstie; "The Electro-chemical and Electro-metallurgical Industry of Norway," by C. W. Eger; "A Brief History of Electric Pig-Iron Smelting in Norway," by H. Christiansen, Junr.; and "Features from the Planning of an Electric Smelting Plant for Pig Iron in Mo i Rana," by B. Muller. Time was not available for the presentation and discussion of Dr. Görrissen's paper on "The Determination of Red Shortness in Mild Steel."

Brief summaries of the papers follow. Readers interested in seeing them in full will find them in the May issue of the *Iron and Steel Institute Journal*, with the exception of the last two, by Mr. Muller and Dr. Görrissen, which were published in a special English edition of the Norwegian publication, *Tidsskrift for Kjemi, Bergvesen og Metallurgi*.

Papers Presented in Oslo

SOME NOTES ON BRITTLENESS IN MILD STEEL

By Johan Görrissen

THE seriousness of the problem of brittle fracture in chain links is indicated by the fact that, on the average, one chain is broken every day in the harbour at Oslo. The investigation reported in this paper was begun at Christiania Spigerverk in 1939 as a result of the many failures in ship steering chains during the stormy winter season of 1937–38—a contributing factor to the loss of several ships.

In a study of the brittleness of mild steel an important criterion is the transition range temperature, i.e., the temperature range during which the impact value falls from a high to a low value. The importance of having this value as low as possible will be appreciated when the low temperatures encountered in wintry conditions at sea are considered.

In discussing the effect of grain boundary cementite formation, it is pointed out that cementite may be formed in two ways. In the first, decomposition of pearlite results in the formation of thick bands or spheroids of cementite and, being dependent on diffusion, the process is rather slow. On the other hand, in carbon lean areas, thin grain boundary layers of cementite are formed so quickly that diffusion cannot be the mechanism. It is assumed that dislocation in the boundary can accommodate more carbon than the α- lattice itself and that diffusion is therefore not a necessary requirement for precipitation.

Considering the results of a large number of experimental treatments in which the effects of annealing temperature, cooling rate, prior cold work, composition and deoxidation methods were varied, it is concluded that, regardless of other structural differences, the ferrite grain size is the dominating factor in controlling the transition range in annealed steels. The possibility cannot be overlooked, however, that the spheroidic cementite formation, which is typical of fine-grained steels, might be of considerable importance.

As chains are subject to severe handling and consequent reduction by cold work it is essential that they should be annealed above the A_3 point to avoid excessive grain growth. The cooling rate is also important. By fast cooling rates the transition range temperature is lowered, partly due to a finer ferrite grain size and partly to a more beneficial pearlite cementite structure. Slow cooling rates, which are sometimes advocated for mild steels, are detrimental to impact properties and should be abandoned. Cooling in air is better, but cooling in oil or water give the best results, with a preference for the former as it provides some corrosion protection.

Although fairly good results are obtainable by annealing above A_3, followed by a fast cooling, the unkilled mild steels are not considered as ideal chain materials. The transition temperature is too easily transferred to higher temperatures and too fast a cooling rate may also induce embrittlement due to quench ageing. Steels less susceptible to embrittlement can be produced by alloying with silicon and manganese, a suitable composition being Si 0·05–0·30% and Mn 1·25–1·50%. Up to 0·25% carbon does not seem to affect the impact values. Aluminium also has a marked and beneficial effect, both in controlling the grain size and in reducing the liability to ageing.

EXPERIENCES IN THE STUDY OF ISOTHERMAL TRANSFORMATIONS

By T. F. Russell, F.I.M. and C. Mavrocordatos, B.Met.

WHILST the use of inverse rate curves is still one of the best methods of determining the change points on heating a steel, the reactions on cooling may be so complex that it is extremely difficult to interpret the inverse rate curves. Accordingly, in the author's laboratory, inverse rate cooling curves were abandoned some ten years ago in favour of studies on isothermal transformation. In the present paper, a few of the points raised during that period are discussed.

In the determination of T–T–T curves it is necessary, in the case of certain steels, to follow the transformation over periods up to 100 hours or more and for this purpose the authors describe a magnetic recording method based on the increase in magnetic induction as the austenite transforms.

By the use of this equipment, it was shown, many years ago, that the austenites of some steels show remarkable stability at temperatures between the pearlite range and the intermediate range and also stability of partial transformation in the latter range. The apparatus has its limitations, however. In a plain carbon steel the magnetic change point is above the carbide change point but, with certain alloying additions, it is possible to raise the carbide change point above the magnetic change point and it has been shown that the austenite of a 3% chromium steel may change completely to pearlite in the non-magnetic condition.

Most of the work in the authors' laboratory is now done by the dilatometric method which has several advantages. Although it is rather difficult to make very accurate measurements of length changes, examination of a large number of results should bring into prominence any well-defined tendencies and in the second section of the paper some general comments on length change are given as the result of a recent re-examination of dilatation curves taken during the ordinary course of work on isothermal transformations. A knowledge of the volume changes which take place when a steel is transformed is essential for the calculation of stresses set up during cooling. It should also be possible to detect the beginning of precipitation of pro-eutectoid ferrite or pro-eutectoid carbides as the former causes an expansion and the latter a contraction. Examination of the dilatation curves of hypo-eutectoid steels, in the higher temperature range, showed suggestions of the effect of ferrite precipitation, and replotting the percentage transformation, on a probability scale, against time on a logarithmic scale gave confirmation in the form of an abrupt change in direction. In the case of hyper-eutectoid steels there was no definite indication of discontinuity, probably because the effect is so much smaller.

Plotting the change in length against the temperature fraction $A_e–B_t/A_e–M_s$, where B_t is the bath temperature there is a definite separation of the hypo- and hyper-eutectoid steels into two groups, the lower carbon steels showing a greater expansion than the higher carbon steels. This follows naturally from two well-known phenomena: when α iron changes to γ iron there is contraction in volume, and when carbides dissolve in γ iron there is an expansion. The effect of other elements, up to 3%, seems to be insignificant, and there is no doubt that the change in length or volume depends predominantly on the amount of carbon present in the steel, or to be more exact, on the amount of carbon dissolved in the austenite at the austenitising temperature. With low austenitising temperatures, at which some of the carbide is not in solution, the length changes are appreciably increased.

DETERMINATION OF AN ISOTHERMAL TRANSFORMATION DIAGRAM WITH AN OPTICAL DILATOMETER

By J. K. L. Andersen, Met. Eng.

IN the Leitz optical dilatometer, a standard rod of Cronin and a sample rod are placed in parallel quartz tubes. The change in length of each rod is transferred through quartz rods to a plate and thence to a prism supported at three points, of which two are movable and one fixed. A beam of light is reflected from the prism on to a sensitive photographic film or paper. As the rods are heated, the horizontal axis will represent the change in length of the Cronin rod, and the vertical axis of the sample. As the thermal expansion coefficient of Cronin is known, the horizontal axis also indicates the temperature. In dealing with isothermal transformations the time factor has to be considered. If the temperature is held fixed the luminous point will describe a straight line parallel to the ordinate and in this way the elongation can be determined only at the moment the experiment is stopped. The time factor has been introduced in a novel way: the cassette holding the film or paper can be rotated at constant speed during the isothermal transformation, so that the luminous point describes a spiral, the number of turns giving a measure of the time. When the transformation is nearly complete and the rate very slow the spiral will change to circles which overlap. To avoid excess of overlapping, the rate of revolution may be decreased. From the resulting curve the time to complete any desired percentage of total transformation can be readily determined. At most a relative error is possible of 0·5% due to shrinkage of the paper on processing. The transferential errors on the dilatometer amount to 0·2–0·3% "absolute."

THE ACCELERATION OF THE RATE OF ISOTHERMAL TRANSFORMATION OF AUSTENITE

By M. D. Jepson, M.Sc., and
F. C. Thompson, D.Met., M.Sc., F.I.M.

IN the first part of this paper, the effect of a fluctuating temperature, in the transformation bath, on the rate of transformation of austenite is discussed. A marked decrease in the transformation time was observed in the martensite range and it was found that most of the transformation occurs during the cooling part of the temperature cycle.

When partial transformation of austenite occurs, particularly to martensite, there is a marked tendency for breakdown to occur preferentially at the surface. Benedicks suggested that the skin of martensite first formed retards further expansion in the interior and thus, together with any compressional stresses set up, inhibits further breakdown. It seemed likely that the imposition of a tensile stress during transformation would tend to facilitate the transformation of the specimen as a whole.

A series of experiments in which the specimen was stressed, either in tension or compression, during the transformation, show that a marked acceleration of transformation rate results from the application of tensile stresses of the order of 10 tons/sq. in. Compressive stresses of a higher order are required to produce a comparable effect. Below a certain minimum stress, little or no acceleration occurs and the increase in rate of transformation becomes greater as the stress is increased. The course of the transformation was followed microscropically and by measuring the load required to break notched test-pieces, a method which has some promise.

Apart from the acceleration, transformation under stress, to low temperature bainite, is marked by certain distributional effects, transformation taking place preferentially on slip or twin bands present in the parent austenite. Prolongation of the thermal and stress condition, for a time in excess of that required for complete transformation, results in a clarification of a granular structure and increased definition of the twin bands. This implies some further change is taking place.

It is suggested that the formation of low-temperature bainite is due to the combined action of shear and nucleation, the transformation being initiated by the former and continued by the latter. The importance of the two effects varies with temperature, nucleation being of greater importance at higher temperatures and shear the more important at lower temperatures. The effect of stress in the pearlitic range, including transformation to higher temperature bainite, is to produce, by deformation, extra nuclei of α-iron.

THE PROPERTIES OF OLIVINE AND ITS USES FOR REFRACTORIES AND MOULDING SANDS.

By K. J. Stenvik

NATURAL olivine and olivine rocks, of which there are important deposits in Norway, have been known for some time to have valuable refractory properties, despite their content of Fe_2SiO_4 which is extremely fusible in the pure state. The main constituent is Mg_2SiO_4 and Goldschmidt showed that natural olivine rocks with as much as 10% Fe_2SiO_4 could stand up to temperatures (under load) well above 1,700° C. The development of olivine refractories for industrial uses took place largely from 1928–1931 when refractories were made according to Goldschmidt's methods by transforming olivine rock into a mixture of forsterite (Mg_2SiO_4) and magnesium ferrite. Forsterite bricks are now used in the roofs of copper holding and copper reverberatory furnaces. In the steel industry they give satisfactory service in the end wall, bridge wall, and other parts of open-hearth furnaces. They are also used in cement and ceramic kilns. The main properties of forsterite bricks are given and comparison is made with other refractories.

Although preliminary tests had shown the technical possibility of using olivine as a moulding sand, its development followed that of the olivine refractory bricks. Best quality olivine is substantially more refractory than is quartz and also shows greater resistance to scorification of iron oxides, thus preventing the incrustation of sand and scoriæ on the surfaces of castings. To benefit from the advantages of olivine it must be protected from contamination by such materials as quartz sand, granite, felspar, talcum, limestone and aluminous substances. As a bond, only certain special clays, for instance, the American Wyoming bentonite, the Coldbond, and the Ball clay, can be used and then only in very small amounts.

One of the advantages claimed is that the inhalation of dust from olivine will give only very slight or no risk of silicosis. This may be due to the fact that, unlike crushed silica, olivine has no free valences in the surface structure of the dust particles.

Papers Presented on the "Venus"

THE MANUFACTURE OF ELECTRIC STEEL IN GREAT BRITAIN

By the Electric Process Sub-Committee of the Steel Making Division of B.I.S.R.A.

IN a paper such as this, which contains a considerable amount of detailed information, it is only possible, in the space available, to deal with a few of the points raised.

For ingot production, the largest furnaces in operation have a capacity of 30–35 tons but more shops have furnaces of 10–15 tons capacity than of any other size. Preference is given, in these days of demand for large output, to furnaces arranged for top charging, although there is something to be said for mechanical charging of the bigger furnaces. Several oscillating-hearth furnaces are in operation but whether the advantages outweigh the complications is a moot point. A general trend in design is towards the easier and more rapid servicing of the furnace and refractories. Most British furnaces use graphite electrodes but, owing to high cost, increasing interest is being shown in the Söderberg self-baking electrode. The three methods of charging in general use, *viz.*, hand, basket, and machine, are used on small, medium and large furnaces, respectively. Where the furnace can be loaded with one removal of the roof, the basket method has much to recommend it, but in other cases mechanical charging is to be preferred. The latter also facilitates a better scrap distribution and the addition of comparatively large quantities of alloying or slag-forming materials. With the exception of the smaller furnaces used in foundries, arc furnaces in Britain are of the basic type and much work has been carried out on the refractory problem with the result that there is a tendency towards the all-basic furnace.

Details are given of 30 typical arc furnaces in use in Britain and practice in one arc-furnace and one induction-furnace plant is considered in some detail. Reference is also made to the use of both types of furnaces in the foundry, particularly for alloy steel castings.

The future of electric steelmaking in Britain depends largely on the relative costs of electric power and other fuels. As coal is likely to be the main national source of power it seems unlikely that electricity prices will fall appreciably. Nevertheless, the unique advantage held by the electric process in the production of low sulphur steels is of great importance at a time when open-hearth fuels are tending to increase in sulphur content. Already a number of British firms have made a series of trials on less-specialised steels, sometimes working a single slag process as in the open-hearth furnace. Under these conditions the costs have been reduced, even competing with the open-hearth process. One plant is successfully making low-sulphur rimming steel for deep-drawing purposes.

The possibilities of using oxygen for cutting down solid scrap on the banks and for carbon removal are being investigated with the object of determining what economies can thereby be effected. Other developments include the use of duplex processes combining converters and cupolas with the electric furnace.

There is no doubt that the electric furnace output of the country will increase but it is probable that the percentage of the total steel output made by the electric process will remain about the same.

THE SÖDERBERG ELECTRODE SYSTEM

By H. Christiansen, Jnr., and B. Ydstie

THE use of the Söderberg electrode in electro-metallurgical work has increased rapidly during the last twenty years. Prepared from green electrode paste and baked by waste heat from the furnace the electrode may be renewed without interrupting the furnace operation.

Electrode paste is made by mixing suitably granulated metallurgical coke or anthracite (calcined to remove volatiles) with a tar pitch binder at 150–180° C. and casting into 60 lb. blocks. The electrode proper is formed by the open-ended sections (6–7 ft. in length) of cylindrical or rectangular, internally ribbed sheet steel casing which are welded on top of each other and filled with electrode paste. As the lower end is consumed, the electrode is periodically lowered through the clamps. This slipping is controlled by the " Wisdom " brake and can be carried out under full load with perfect safety. When the top of the electrode comes level with the Wisdom gear it is filled with paste and a new section of casing mounted. The bottom end of the electrode is baked by the heat from the furnace and by the passage of current whilst the upper part remains in a pasty condition. One advantage of the Söderberg type of electrode is that it can be made in larger sizes than pre-baked electrodes are made at present. The electrical conductivity is increased by the steel casing and internal ribs and for that reason it may be operated at higher current densities than the pre-baked type of electrode. The casing is also of assistance where the electrode is subject to excessive wear. Electrode consumption is about the same as with pre-baked electrodes.

In steel furnaces the electrodes are subjected to greater strain than in smelting and fully satisfactory operational results can only be obtained when using first-class electrode paste.

In the electrolytic aluminium reduction process rectangular Söderberg electrodes with an aluminium casing are used. The current is carried to the electrode by means of contact stubs laterally introduced into the plastic paste above the baking zone and extracted just above the electrolyte. During the last few years a new system has been developed whereby the current is introduced and the electrode is suspended by vertical contact stubs and is shaped and baked in a permanent steel casing. For the aluminium process it is essential to use materials with a low ash content, such as petroleum coke, for the paste manufacture.

THE ELECTROCHEMICAL AND ELECTRO-METALLURGICAL INDUSTRY OF NORWAY

By C. W. Eger

THE electrochemical and electrometallurgical industry dates back to the beginning of the century, when industrialists in Norway and elsewhere realised the potentialities of the country's large water-power resources and the numerous and excellent ice-free ports. The first important steps towards the development of the industry were made during the years 1905 to 1912 when large plants were established for the fixation of atmospheric nitrogen. Examples of other processes developed in Norway since that period include the nickel refining process at Falconbridge, electric copper-smelting at Sulitjelma and the Tysland-Hole electric processing of iron ores. The products of the wide variety of electrochemical and electrometallurgical processes operated embrace, in addition, fertilizers, calcium carbide and cyanamide, silicon carbide, alkali chlorates, electrolytic zinc, electric steel and aluminium. At Höyanger, alumina, for the aluminium plant, is made by smelting bauxite in electric furnaces by the Pedersen process. A high quality pig iron is produced as a by-product.

The electrochemical and electrometallurgical plants of Norway, of which more detailed information is given in the paper, are producing to the fullest extent with the power that is available ; as new hydro-electric stations are erected, so will production at existing plants be increased. In addition new works may be built, but the the present unsettled conditions make it difficult to forecast with accuracy any future developments. Apart from the expansion of the nitrogen industry and the erection of a new iron and steel works at Mo i Rana, an increase in capacity of the ferro-alloy and aluminium industries is contemplated.

Power projects, both those at present under construction and those which are being planned, will involve much greater expense than would similar projects before the war. However, owing to the general rise in prices, the favourable relationship between power costs in Norway and those in most other countries, is likely to be maintained in the future. Furthermore, the output from most Norwegian power plants is constant throughout the year—a factor of considerable importance to the industry. It is therefore reasonable to expect further expansion in Norway of this and other industries which are dependent on the constant availablity of large quantities of cheap power.

A BRIEF HISTORY OF ELECTRIC PIG-IRON SMELTING IN NORWAY

By H. Christiansen, Jnr.

THE growing competition of coke blast furnaces resulted, about 1850, in the closing down of the small Norwegian charcoal furnaces which used to produce high quality pig iron. Norway never built any coke blast furnaces and it was not until the early years of the present century that the discovery of large iron deposits and the development of the country's water-power resources gave impulse to the study of methods for the electric smelting of pig-iron.

In 1910, an electric pig-iron furnace using coke as a reducing agent was erected at Tinfos and a similar one was erected at Ulefoss in 1913 but owing to various unsatisfactory features of design no further installations were undertaken. About the same time, the Swedish 'Elektrometall' high shaft electric pig-iron furnace, designed to be operated on charcoal was achieving considerable success. Two such units were erected at Tyssedal, but the plant was closed after two years as there was no local charcoal and the furnaces proved unsatisfactory when operated on coke.

Ten years later, in 1922, the Norwegian Government financed a new series of tests on the electric smelting of iron ores with coke. These were carried out by G. Tysland at A/S Fiskaa Verk. Christiania Spigerverk and Elektrokemisk A/S participated in the running of the tests which proved so successful that Christiania Spigerverk erected a 6,000 kva furnace based on the experience obtained. Following modifications by I. Hole, in 1927, the furnace was in continuous operation until it was dismantled last year.

The furnace is a closed low-shaft furnace equipped with three Söderberg electrodes and it can be operated on such cheap materials as gas-coke and coke-breeze. A 9,000 kva unit was installed at Bremanger in 1927 and some 22 other Tysland-Hole or Spigerverk furnaces have since been built in other countries. They are designed and marketed by Elektrokemish A/S and the largest to date are of 13,200 kva, corresponding to a daily output of about 90 tons.

Furnaces of 18,000–20,000 kva are now in the design stage for the new Government-sponsored iron and steel works at Mo i Rana where it is intended to produce 200,000 tons of electric pig-iron per year. The first unit is expected to be in operation in 1953 and the operating reports from the plant will be awaited with interest insofar as they will indicate whether the building of still larger furnaces is a practical proposition.

FEATURES FROM THE PLANNING OF AN ELECTRIC SMELTING PLANT FOR PIG IRON AT MO I RANA.

By B. M. Müller

THE plant discussed in this paper forms part of the new iron and steel works in course of erection at Mo i Rana, in northern Norway, under the auspices of A/S Norsk Jernverk, a government-sponsored company. This plant is not yet built and the author has confined himself to a discussion of some of the problems encountered in planning and of their solutions.

It is intended, as a first stage of development, that the electric smelting plant should provide sufficient iron to cover a rolling programme of 150,000–200,000 tons a year, with a possible future increase to 500,000 tons a year.

One of the most important questions to be decided was the size of smelting furnaces to be adopted. Initial plans were for 20,000 kw. furnaces supplied by power from an existing generating station at 25 cycles. Unfortunately the power from that station was allocated for other purposes and it was decided to construct a new station to supply power for the iron works and civilian use in the districts around the Rana Fjord. This would seem to suggest that either there should be two supplies, one at 25 cycles and one at 50 cycles or that the 20,000 kw. furnaces should be abandoned in favour of smaller furnaces in view of the low power factor at 50 cycles. The possibility of power factor correction by means of capacitors was, however, considered, and in spite of the fact the installation of such equipment on a large scale would be an expensive undertaking, it was calculated that would be an economical procedure compared with having two supplies or using smaller furnaces.

A further problem to which considerable attention has been paid is that of ore preparation. The production is to be based on the extensive ore deposits of the Rana district. A new large scale mining and separation plant is projected but for the first few years operation it will be necessary to use ores from A/S Sydvaranger in Kirkenes and Fosdalen Bergverksaksjeselskap near Trondheimsfjord. The ores from the three sources are alike in that they are all produced in the form of fine concentrates with 65–68% iron. They differ, however, in their contents of other important elements and, what is more important, in the grain size. The Fosdalen concentrates are sufficiently coarse grained for sintering whilst the Sydvaranger concentrates are too fine grained and must be rolled into pellets. As the separation process to be used on the Rana ores is not yet decided it is not certain whether the concentrates will be fine or coarse grained. After due consideration, and extensive sintering experiments, it has been decided to install a Greenawalt sintering plant, if necessary.

Details are given of the burdening of the smelting furnaces, which are to make iron suitable for blowing in the acid Bessemer converter, and of the raw material handling plant.

The gas from the smelting furnaces will be cleaned and stored for use in the works and it is expected that the quantity and quality will be sufficient to meet the whole demand for fuel in the rolling mills and other sections of the works.

In the first stage of erection the planning comprises four smelting furnaces, although not more than three will be installed at the start. It is foreseen that production may increase to some 500,000 tons of pig iron at some future date, in which case a further four furnaces will be installed.

DETERMINATION OF RED-SHORTNESS IN MILD STEEL.

By Johan Görrissen.

THE main object of the paper is to discuss methods for the determination of red-shortness in mild steel. These include: (*a*) Forging out the edges of a flat bar; (*b*) upsetting tests; (*c*) hot bend tests; (*d*) hot notch bend tests; and (*e*) hot notch impact tests.

At the author's works the notched bend test was formerly used but had been found to show a certain lack of dependability, possibly for the following reasons:

The test is carried out on material which has been strongly heated, and even overheated during heating for a forge-welding test. Further the depth of the notch, cut by a sharp chisel, is rather indefinite.

A modified test was therefore devised in which a sharp notch of definite depth and angle is cut by a sharp chisel at 900°–1,000° C. The test piece is then soaked at 800° C. and the notch forced open by a 90° rounded "chisel" of definite dimensions, and the severity of cracking at the bottom of the cut is compared with a standard scale. Furthermore, as the cracks caused by red-shortness are formed most easily in the core, where non-metallic inclusions and phosphorous are concentrated, the test is applied in the middle of an end face of the material. According to the author's investigations, red-shortness may occur both in the $\alpha + \gamma$ zone and in the γ zone.

Although the paper was not intended to discuss the causes of red-shortness, mention is made of a few points of interest in this connection.

It is generally accepted that hot shortness increases with sulphur content, but the extent has been found to vary with heating procedure and use has been made of this fact by soaking ingots of free-machining steel for 1–1½ days before rolling.

Dissolved gas may also influence red-shortness and Hatlanek considers CO_2 to be the most harmful gas followed by CO and, lastly, hydrogen. The author has found, time and time again, that a steel tested immediately after hot forging may show less red-shortness if tested after an interval of a few months and it is thought that the presence of hydrogen may be responsible.

The Institute of British Foundrymen

Forty-Sixth Annual Conference held at Cheltenham

Gradually the problems associated with the production of castings are being approached scientifically, and the Institute of British Foundrymen, since its inception, has been the instigator of much of the progress achieved in the foundry industry. The technical sessions at the recent conference, which are briefly summarised in the following notes, indicate the wide range of subjects discussed. In addition to the approach to technical problems, however, it is noteworthy that the need for solutions to human problems was emphasised, with a view to establishing good relations between employers and employed.

THE Forty-Sixth Annual Conference of the Institute of British Foundrymen, held at Cheltenham on June 14–17 inclusive, proved an outstanding success. The Conference was well attended, the weather was delightful, the business and technical sessions and the works visits were of real constructive value, the social arrangements for members and their ladies proved most enjoyable, and the selection of Cheltenham Spa was a happy choice. The general spirit of friendliness and co-operation prevailing at this meeting and the interest displayed at the technical sessions and works visits augur well for the continued success of this Institute.

The members and their ladies were welcomed by the Mayor and Mayoress, Ald. and Mrs. P. T. Smith, at a reception given by the Corporation of Cheltenham at the Old Town Hall, at which the Mayor, in a short speech, wished all concerned with the Conference a happy and successful time spent in the town and its environs. Mr. Templeton, responding, expressed thanks for the manner in which the Institute had been received. Several artists provided music and entertainment during the remainder of the evening.

The business meeting was held in the morning of June 15th in the Pillar Room, Town Hall, the retiring President, Mr. R. B. Templeton, being in the chair. Annual reports of the Council and of the Technical Committee were received, which indicated the high level of activity maintained. It is noteworthy that membership continues to increase, it being 4,380 at the end of April this year. As a result of an offer by the Joint Iron Council to reimburse certain expenditure incurred by additional work to be undertaken by the Institute, the work of the Technical Council and its Sub-Committees has been extended. Reference is made to this grant in the report of the Technical Council.

Presentation of Awards

Oliver Stubbs Medal—Mr. G. L. Harbach.

E. J. Fox Gold Medal—Sir Andrew McCance, D.Sc., F.R.S.

Meritorious Service Medal—Mr. Arthur Sutcliffe.

British Foundry Medal—Mr. D. H. Young.

Presidential Address

The outstanding feature in Mr. Newman's inspiring address was the emphasis he placed on human relations in industry. Unless leaders face the human as distinct from the material problems, he said, they run the risk of becoming the helpless slaves of a monster machine of their own creation. He believed that social skill or technique was just as important as material technique in dealing with problems which existed in foundries. Some extracts from his address will indicate that he holds strong views on this question of human relations. This country has passed over the threshold of a new age in social, economic, and political reform. To-day she is faced with the greatest problems in her history and, principally as a result of two world wars, her international credit is weaker than at any time since the advent of the industrial age, in addition she is experiencing the most acute man-power problems, and the most stringent peace-time controls. Had we been as successful in developing the principles of co-operation between people and nations as we have been in developing weapons for human destruction, there would not have been a second world war.

Old beliefs and prejudices must be removed if we are to surmount the difficulties that press upon us. No matter how well our foundries are equipped with modern machines and skilled technicians, they will not function efficiently until all in the industry work together for the common good and with mutual respect and belief in the fundamental rights of man. In the past blame could be attributed to both employers and employees, who, knowingly or unknowingly, did much to foster a spirit of antagonism which still exists in some industries. These misunderstandings and differences have to be swept away and the present leaders of industry must take the initiative in establishing better industrial relations.

The large mass of employees had more fear of unemployment than of any other factor affecting their lives. Many employers on the other hand believed that too much emphasis was placed on stable employment, which politicians could not conjure out of a hat. It must be clearly understood that all must work together to create social security, and this can only be won by enterprise, efficiency, and co-operation at all levels.

In his concluding remarks he declared that to obtain the best results from their industry they must improve and encourage the highest standards in leadership. Machines, scientific methods and controls must be made the servants and not the masters.

Edward William's Lecture

Metal Founding through the Ages

Immediately following the Presidential Address the above Lecture was delivered by Professor Hugh O'Neill, in which he discussed the ancient history of cast metals, particular reference being made to the distribution of finds of prehistoric moulds in the British Isles. Some ancient moulds are also described. He stated that before the Roman occupation of Britain bronze was chiefly imported from Ireland and he considered the trade routes to South Wales and the Severn Valley.

Particulars were given of a fragment of cast copper alloy found near an ancient furnace hearth by the shore at Merthyr Mawr (Glamorgan) and reputed to date from *circa* 350 B.C. which, on analysis, proved to be a leaded brass free from tin.

The history of founding was reviewed and the writer had hoped that Dr. O'Neill would refer to the casting of the pillars for King Solomon's Temple which, from data available regarding dimensions, would probably test the skill of founders to-day. However, his historical review had special reference to work in cast iron and to the use of coal before the Christian era, and to modern developments in casting, particularly to centrifugal and continuous castings and to die-casting. He asserted that historical and æsthetic considerations help to link science with art and should not be ignored by metallurgists.

The Lecture emphasised that founding is one of the ancient crafts and proved both informative and stimulating.

Technical Sessions

Some seventeen papers and reports were presented for discussion at six technical sessions, and in order that this could be effected in the relatively short time available it was necessary to conduct some of the sessions simultaneously. At session A the subjects discussed were stress relief heat treatment of alloy cast iron; the influence of heating rate in malleable iron annealing; and the influence of stripping temperature on the properties of pearlitic grey-cast iron. At session B, which ran simultaneously with A, were discussed some factors controlling the incidence of hot tearing in aluminium casting alloys; some examples of aluminium alloy foundry practice; and some notable aluminium alloy castings. At Session C were presented some experiences with Ethyl Silicate in the foundry; some problems in bronze foundry practice; an exchange paper from American Foundrymens' Society; and mechanical properties of copper-base alloy castings. Session D dealt with work of the Lake and Elliot Foundry Technical Committee; the effect of grain shape on the behaviour of synthetic core and moulding sands; and notes on the hot extraction method as applied to cast iron. Session E was concerned with the production of metallurgical coke; and cupola charge materials. Session F considered the system of costing in a South African foundry; organisation for the training of apprentices in French foundries, an exchange paper from l'Association Technique de Fondarie; and the metallurgical examination of a cannon-ball found after the battle of Lichfield.

STRESS RELIEF HEAT TREATMENT OF ALLOY CAST IRON

MUCH work has been done on the stress-relief of iron castings in recent years, with one or two exceptions, however, the work has been qualitative in the sense that the stresses present were not accurately measured and the reproducibility of the results on stress-relief has sometimes left something to be desired. Furthermore, it was felt that the magnitude of initial internal stresses might well be a factor in determining the amount of stress relief at a given temperature, bearing in mind that the process of stress relief is essentially one of slow plastic deformation—i.e., creep.

During the production of castings in high alloy materials, information on stress-relief treatment has frequently been needed and the present work, by M. M. HALLETT and P. D. WING, which covers a range of high and low alloy cast irons, has been carried out in an endeavour to provide a more complete picture of the whole operation of stress-relief treatment.

It was considered advisable to start with a simple form of test piece, and to impose on it a known stress, and to measure the relief of that stress following a series of planned treatments. A ring form of test piece was adopted because of its simplicity and sensitivity. The rings were parted-off from tubular castings, and were carefully machined to the same dimensions, and a gap of a constant width was cut in all specimens. All the specimens were subjected to preliminary stress-relief treatment at 550° C. for one hour. Compositions of the materials from which the test rings were made are given in Table I.

TABLE. I—COMPOSITION OF EXPERIMENTAL MATERIALS

Element	Composition %			
	STA/8 sand cast	Loded Centricast	33% chrome iron Centricast	Ni-Resist Centricast
T.C.	3·20	3·25	1·35	2·16
Si	2·01	3·01	2·01	2·08
Mn	0·89	0·94	0·68	9·75
P	0·17	0·73	0·10	0·84
Ni	<0·10	<0·10	—	15·19
Cr	0·14	0·55	34·30	1·76
Cu	—	—	—	7·11

As a result of this investigation the authors conclude that in comparatively low-alloy, sand-cast or centrifugally cast iron, over 80% relief of stress may be attained by heating to a temperature of 600° C. for one hour. This is not accompanied by any deterioration in mechanical properties or in microstructure. In high-alloy iron of the 33% chromium and Ni-Resist class, it is necessary to heat to 650° C. to obtain a satisfactory degree of stress relief. This does not affect the mechanical properties of the 33% chromium iron, but may reduce the tensile strength of Ni-Resist by about 10%. The magnitude of the initial stress does not have a predominating effect on the relief of stress at any given temperature but in all four materials there is a tendency for the percentage relief of stress to be higher with a higher initial stress. This is particularly marked in the high-alloy irons at moderate and low temperatures. Prolonging the time of treatment at 450° C. greatly increases the amount of stress relief, but the rate is prohibitively slow. Ageing at room temperature for several months appears to lead to a maximum relief of stress of about 10%. The practice of stress relief by heating to an elevated temperature is, therefore, greatly to be preferred to the practice of weathering at atmospheric temperature.

THE INFLUENCE OF HEATING RATE IN MALLEABLE IRON ANNEALING

RECENT developments in the annealing of malleable cast iron has tended to reduce the length of the annealing cycle in connection with which the introduction of the electrically-heated furnace, using a controlled gaseous atmosphere, is having an important influence. The object of the work described in this paper concerns the influence of the rate of heating on graphitisation after the top annealing temperature has been reached and the dependence of the final structure on the rate of heating. Reference is made to materials reported by the author in a previous paper published in the 1947 Proceedings of this Institute. For the present work the effect of heating rate on both whiteheart and blackheart malleable cast irons was investigated.

Throughout the wide range of chemical compositions that have been used in these experiments to represent whiteheart iron it is apparent that all have responded in a similar manner to variations in heating rate. Thus, irrespective of silicon content and the sulphur to manganese ratio, a rapid rate of heating, in general, gave a limited number of large nodules and a slow heating rate gave an appreciable increase in the number of nodules, the size of these being much smaller.

When a whiteheart iron has a high manganese content or a high sulphur content especially in conjunction with a low silicon content, the danger of the persistence of eutectic cementite in the annealed material is considerable. Therefore, with all other conditions being the same, embrittlement of the annealed material by un-decomposed cementite tends to be avoided with relatively slow rates of heating. This is especially important in thick sections where de-carburisation has had little or no effect.

It is shown that blackheart materials are very sensitive to variations in the rate of heating to the annealing temperature. Whereas a rapid heating rate leads to the occurrence of a relatively small number of large dispersed aggregates and produces material which is difficult to anneal, particularly during the second-stage period, a slow rate of heating results in the formation of numerous small compact aggregates to give material in which eutectic cementite decomposition proceeds readily and in which secondary graphitisation during the second stage portion of the anneal is achieved without difficulty.

THE EFFECT OF STRIPPING TEMPERATURE ON THE PROPERTIES OF PEARLITIC GREY CAST IRON

WITH increasing rates of production, particularly in mechanised foundries, there is a tendency for castings to be stripped from the mould soon after they have been poured, and while they are still at relatively high temperatures. Following variations in the properties of certain iron castings produced during the war, some fears existed as to the possible effects of high temperature stripping on the mechanical properties of the castings and on their liability to distortion. In order to investigate these questions, a Sub-committee was appointed by the Technical Council with the following terms of reference :—" To study the influence of stripping temperature on the structure and properties of pearlitic grey cast iron." The present report was submitted by that Sub-committee.

The test-bars employed for the determination of the mechanical properties were 2·1 or $\frac{7}{8}$ in. diameter, British Standard bars, cast vertically in oil-sand moulds and top-poured through a tapered feeding head. Experiments on the 2·1-in. diameter bars were made on two materials. The first was a low-silicon unalloyed iron of the type on which the determinations of cooling rate had been carried out earlier. The second was an iron alloyed with nickel, chromium and molybdenum, since it was thought that such an iron would show more strongly any effects resulting from stripping at high temperatures. The range of stripping temperatures was wide, from 950°–20° C.

A series of tests was carried out in a corresponding manner on the $\frac{7}{8}$-in. diameter bars, again following the same procedure as was used in determination of the cooling curves. These tests were confined to an unalloyed iron of a silicon content to suit the section.

The results described in this Report show that, on the whole, the changes in the characteristics of castings, resulting from changes in stripping temperature over quite a wide range, are not very marked. There is a clear tendency for slight air-hardening to result, when castings of medium section are stripped from the mould while still at a high temperature above the critical point. The air-hardening causes a small increase in tensile strength, and an increase of 20–40 points in the Brinell hardness value. Other properties tend to vary in an irregular manner, and do not always show any clear change. Stripping at high temperatures does not cause notable changes in castings of thin section, below, say, $\frac{1}{2}$ in., since in these sections the rate of cooling in the sand mould is not very different from that in still air.

The effects of stripping at a high temperature on consequent distortion, while subject to general principles, are more complex in their operation and would have to be determined for each particular casting. Apart from the obvious danger of handling the casting while extremely hot, it does appear that a high stripping temperature reduces distortion and internal stress in a casting containing widely spaced limbs differing in their section. Where the limbs are in closer proximity, and do not differ very markedly in section, stripping at a high temperature might even lead to greater distortion.

FACTORS CONTROLLING THE HOT-TEARING OF ALUMINIUM CASTING ALLOYS

IN this paper by D. C. G. Lees particular attention is directed to exhaustive studies, made during the past few years, of the factors controlling the incidence of hot-tearing in aluminium alloys. Super-purity aluminium and the eutectic alloys do not show tearing even when cast under severe restraint ; initial additions of alloying elements, such as silicon or copper, introduce tearing which increases and reaches a maximum at about the limit of solid solubility under the conditions of freezing, subsequently decreasing and falling to zero. Cracking at temperatures below the solidus is a function of brittleness in the solid state and is unusual in aluminium alloys in normal practice. Hot-tearing has been shown to take place above the solidus.

The factor principally controlling the severity of tearing is the extent of the brittle range of temperature from the point at which the alloy first becomes coherent to the effective solidus under the relevant conditions. In this range, where the primary dendrites have grown sufficiently to interlock with each other and in which there remains a certain amount of residual liquid, the alloy is brittle and liable to crack under the influence of stresses set up by the restraint of free contraction or by premature handling. On passing the effective solidus, the alloy gains a measure of ductility.

Under favourable conditions, the author states, cracking may be averted by the process of accommodation—

i.e., slight re-arrangement of the grains before freezing is complete and, further, by the flow into incipient cracks of eutectic liquid derived from portions of the casting in which freezing is less advanced. Thus, freedom from hot-tearing may be regarded as being a function of the extent of the brittle range (which is somewhat similar to, but not identical with, the freezing range) or of the proportion of eutectic present—both constitutional factors. Further, any factors influencing the distribution of residual liquid may affect the incidence of hot-tearing. Among these must be mentioned grain size and gas content. Grain refinement, which reduces the severity of tearing, may be operative either by changing the distribution of the eutectic liquid or, alternatively, by easing the process of accommodation. Dissolved gas released during freezing may also reduce the severity of tearing in alloys not greatly prone to the defect by displacing eutectic liquid from the interstices between the primary dendrites into the intergranular space, thus facilitating accommodation.

EXAMPLES OF ALUMINIUM-ALLOY FOUNDRY PRACTICE

THE growth of the aluminium industry has occurred because of the economic and technical merits of the material, combined with the progressive policies of development which were pursued. To-day, aluminium-alloy castings are produced by all of the recognised methods, in single units or in quantities, of simple and complex designs, in weights up to 35 cwt., to extremely rigorous standards of quality in terms of internal soundness and dimensions. They are used in every conceivable environment.

In this paper by J. Caven and H. W. Keeble they describe the production techniques of certain castings and then review the production and technical backgrounds on which the principles of the techniques are based. In the first part, for instance, production methods are briefly reviewed. The second part deals with factors which affect the behaviour of aluminium alloys in the foundry, the chief of which being gas content; shrinkage characteristics; and chemical and physical properties. To minimise gas absorption, the authors state that metal temperatures should be held as low as possible, the oxide film on the molten metal should not be broken any more than is necessary (for it appears to act as a sealing), and all possible means whereby water vapour can come into immediate contact with the metal should be excluded. If a melt has an excess gas content, treatment with an organic chloride preparation is as effective a method as any for everyday use. A very effective method where really-low gas contents are believed desirable is to allow the molten metal to stand for extended periods.

The volume shrinkage for aluminium alloys is from 6–8%, an exception being the eutectic silicon alloys for which the value is 3·5%. Unless there is available an adequate reservoir of liquid metal outside the limits of the finished casting, this shrinkage will result in unsoundness. The gating and risering system must always be arranged, as far as possible, to push this shrinkage back to the feeding reservoir and this means creating a temperature gradient towards these reservoirs.

The third part gives examples of production techniques in which a Sandslinger and moulding machine are used in a closed circuit in which some excellent examples are described and illustrated. Various sand moulding and die-casting procedures are included in the general review.

SOME NOTABLE ALUMINIUM-ALLOY CASTINGS

FURTHER outstanding aluminium-alloy castings are described in a paper by A. R. Martin who first deals with the characteristics of the alloys used. These are the two binary aluminium alloys containing 10% magnesium and 4½% copper, respectively, the former specification DTD 300 and the latter DTD 298 and 304; the eutectic 12% silicon alloy BS 2L33 and "Y" alloy, and a 5% silicon, 1·5% copper, 0·5% magnesium alloy, specifications DTD 272 and 276.

Two examples of high strength sand castings described are in DTD 300, they comprise a bomb-rack casting for a fighter bomber and two ordnance castings of a similar type, which presented a problem in core-box design. First in the gravity die-cast section are a range of sink units cast in BS 2L33 alloy with a double or single draining-board cast integrally. This range of castings, because of their size, presented a problem in die distortion as well as a problem in casting technique. An intricate high-strength die-casting in DTD 300—an aircraft rudder pedal (also replacing a built-up component)—affords an illustration of how die design and casting technique can overcome the susceptibility of the alloy to contraction and handling cracks.

Further examples of high-strength gravity die-castings are afforded by an aircraft-engine support member cast in DTD 300—almost an ideal design for a die-casting—and a range of tool-holders and pulley wheels, for large capstan lathes, cast in the DTD 304, alloy. In the heat-treated condition, corresponding to DTD 304, this alloy has a higher proof stress than DTD 300, which is essential for giving the rigidity required in this application.

Finally, two examples of cylinder-head technique are provided by a sand-cast head of a four-cylinder motor-cycle engine and a die-cast air-cooled aircraft engine cylinder-head. The motor-cycle head, owing to its complexity, is built up in a simple-cavity mould from fifteen cores. In addition, since the head is jig-machined, strict dimensional tolerances had to be adhered to, and the means whereby the various cores are located are ingenious. The air-cooled aircraft-engine head is a good example of what may be achieved in the way of cooling-fins cast under vacuum.

EXPERIENCES WITH ETHYL SILICATE IN THE FOUNDRY

ORGANIC silicate materials have received much prominence during the last few years, and one of them—ethyl silicate—is described in a paper by D. F. B. Tedds. The earliest application of the silicon esters, of which ethyl silicate is one, was for the preservation of artistic and architectural stone work. Later it was used for bonding together refractory bodies in the form of a paint; then, just before the second world war, it was used for making refractory shapes and moulds. The reason it finds its usefulness in these applications is that, after certain chemical reactions have taken place, silica is deposited, the liquid turns to a jelly-like mass, and sets hard in a comparatively short time.

More recently ethyl silicate has been successfully used in the precision investment casting process, and the author discusses its usefulness in this process, emphasising some of the defects encountered. The use of ethyl silicate for such ancillary applications as furnace linings, refractory shapes, washes, etc., is given. Finally, a method of core making is suggested, which has a limited scope for small- or medium-sized cores, its greatest advantage being that it eliminates the use of compounds, which generate large quantities of gas. It is concluded that ethyl silicate can be used to advantage for certain applications in the foundry.

MECHANICAL PROPERTIES OF SOME COPPER-BASE ALLOY CASTINGS

At the present time no useful information is available on the mechanical properties of typical commercial copper-base alloy castings, and the work described in this Report, from the Technical Committee of the Association of Bronze and Brass Founders, was undertaken to provide such data. It seemed desirable in the first instance to take typical samples of various types of casting from normal production, and accordingly members of the Association of Bronze and Brass Founders were invited to carry out certain specified tests on sample castings from their current production. Twelve members of the A.B.B.F. carried out the required tests on castings taken from their regular production, and the data are summarised in this Report. The scope of this preliminary survey was as follows :—

Types of castings examined : (*a*) Simple forms—bearing bushes, gear wheels ; (*b*) structural members—brackets ; (*c*) castings for hydraulic service—valve bodies, and (*d*) chill castings and chill-cast sticks and bushes.

Alloys : Under the classes (*a*) Phosphor-bronze or gunmetal ; (*b*) and (*c*) gunmetal, high tensile brass, aluminium bronze, and (*d*) phosphor-bronze.

Data recorded : (*a*) Casting records to include (i) Metal composition ; (ii) casting temperature ; (iii) photographs or drawings of castings, wherever possible, showing details of method of running and feeding, and (iv) properties of sand used for moulding.

(*b*) Mechanical and other properties to include (i) Tensile tests on separately-cast test bars ; (ii) pressure test on the casting, where applicable ; (iii) density of test-bars and of specimens cut from the casting ; and (iv) tensile, hardness and impact tests on specimens cut from recorded positions in the casting, the tensile data including 0·1 and 0·5% proof stresses.

The complete data were not available in all cases, the notable omissions being density, impact and proof-stress data. In many cases yield points were quoted ; these are recorded under the 0·5% proof stress heading and they are indicated with an asterisk because the strains to which they correspond were not accurately defined.

The scope of the work was necessarily limited because of the costly sectioning and testing required and to a lesser extent because of difficulties in withdrawing sample castings from current production. Consequently the number of results available for any one type of casting is too small to warrant any definite conclusions being drawn, although a few observations may be offered.

In the first place, it is generally believed that castings in alloys with a short freezing range, the so-called high-shrinkage alloys typified by aluminium bronzes and high-tensile brasses, can be made completely sound and with properties equal to those of separately-cast test-bars with similar cross-section thicknesses, provided the metal is not gassy and castings are properly fed.

The test results for these alloys support this view, although it will be observed that some of the high-tensile brass specimens cut from the castings have poor mechanical properties ; in these cases the castings involved were of such a design that the parts from which the specimens were cut could not properly be fed.

On the other hand, it is well known that alloys with long freezing ranges are liable to contain dispersed porosity which reduces their mechanical properties, although not necessarily to such an extent as to impair seriously their serviceability. The tests on the valve and pump bodies illustrate the latter point ; the castings concerned, or their duplicates, passed pressure tests satisfactorily although some of the tensile test specimens cut from the castings had much lower properties than the separately-cast test-bars.

In alloys of this type, steep temperature gradients are required, in the right directions, to ensure good feeding, and the resulting improvement in mechanical properties is illustrated by the data for the chilled gear blanks and for the chill-cast sticks, the latter having the best properties where the temperature gradients were made most favourable by controlled slow pouring.

An unsatisfactory feature of cut-up tests is that it is impracticable in most cases to test specimens from those parts of the casting likely to have the poorest properties, that is, from parts such as junctions of sections, etc., where solidification is locally delayed.

The main conclusion to be drawn from this preliminary work is that many more tests must be carried out to provide the background of information required by designers and manufacturers of castings in copper-base alloys. Improvements in the quality of castings cannot fail to materialise if data of this kind are made available, because it will enable designers and manufacturers to recognise and avoid bad features in design and unsatisfactory methods of manufacture.

It is recommended that further work should include tests upon a specially designed test casting incorporating the features of a typical production casting but so dimensioned as to permit of full investigation of both properly- and inadequately-fed portions.

THE WORK OF THE LAKE & ELLIOT FOUNDRY TECHNICAL COMMITTEE

This paper by L. W. Sanders, C. H. Kain, R. J. Hart, W. L. Hardy and J. W. Gardom describes some of the work of a small technical committee set up within an iron and steel foundry. There is a discussion of the monthly examination of statistics, relating to " quality " in castings and " economics " in terms of usage of consumable materials. Details are given of researches carried out on cast-steel test-bars, following on previous work with the " cloverleaf " test bar, also the attempts made to establish a reliable and workable machinability test suitable for use by foundries.

Details are given of the development and six-months working of coated moulding sands in an iron foundry, and experience with resin-bonded core sands. Tests of martensitic plough shares are described, also a discussion of sand reclamation for the steel foundry.

Particulars are given of a critical examination of the foundry in the light of the " Report of the Joint Advisory Committee on Conditions in Ironfoundries " and the " Report of the Dust in Steel Foundries Committee." None of the researches has yet reached finality, but it is considered that foundry research is essentially a continuous process, and hasty conclusions should be avoided.

Amenities in the Foundry

FOR some time now there has been a growing realisation in the foundry trade that, if recruitment of labour is to be successful, steps will have to be taken towards improving the conditions of work. To this end various heating, ventilation and dust-control systems have been developed. In the mechanised foundry, with its centralised plant, a combined heating and ventilation system provides an efficient and economical solution but the "jobbing" foundry, with its scattered equipment, presents a much more difficult problem and a combined heating, ventilating and dust-control plant, sufficiently fluid to deal with all air temperature changes in all working zones, is often beyond the realms of practical economics. In such cases, however, it is possible to install local plants, introducing fresh and tempered air to those areas where the need is greatest or removing dust-laden atmosphere at the various points where the condition is created.

The Brightside Foundry and Engineering Co., Ltd., whose Heating and Air Treatment Division are specialists in this type of work, have recently proceeded a stage further in the amelioration of working conditions by the provision of an ablution block for the use of foundry employees at their Ecclesfield works.

At the opening ceremony, which was attended by a number of foundry managers, the Master Cutler, Lt.-Col. J. P. Hunt, T.D., referred to the changing attitude with regard to the importance of cleanliness. The old idea that "where there's dirt there's money" was no longer tenable and it was now realised that cleanliness was the best safeguard of health which in time led to happiness and to a job of work well done. The new ablution block was but one symbol of the new spirit that was abroad in industry.

The most important feature of the block is the adoption of the principle of "clean" and "dirty" sides. Each man has two 3-ft. lockers, one for his clean clothes and the other for his dirty clothes, the two sets of lockers being separated by the bathing accommodation. On arrival at the works he removes his clean clothes, passes to the "dirty side" and dons his working clothes. At the end of the day, he returns his dirty clothes to his locker, bathes and puts on his clean clothes again. In this way there is no possibility of his clean clothes being soiled by using the same locker for his working clothes. The building and each individual locker is disinfected daily.

Accommodation is provided for 180 men and the bathing accommodation comprises 10 shower cubicles, 16 wash basins and 4 foot-baths, each being supplied with hot and cold water. The showers are each provided with a water mixing valve to enable the user to bathe in water of a suitable temperature and the foot-baths are fed through an automatic thermostatically controlled mixing valve.

Each locker is individually warmed and ventilated and for heating the building and lockers a low-pressure accelerated hot-water heating installation is used, the boilers having a combined generating capacity of 1,326,000 B.T.Us. per hour. These boilers also provide heat for the first aid post and cloakrooms and maintain an internal temperature of 70° F. in the block. The hot-water service is supplied from a 680-gallon copper calorifier and supplies water at a temperature of 150° F. to the numerous draw-off points. The boiler plant is designed for both winter and summer use by an auxiliary steam-heated calorifier interconnected to the boiler plant and is supplied by steam from the shop boilers.

The equipment in the block was designed and installed by the Heating and Air Treatment Division of the Company, which has had considerable experience in the installation of pit-head baths at collieries, and the architects were Hadfield, Cawkwell and Davidson, of Sheffield.

The facilities are used in the employee's time and a nominal charge is made which does not, of course, cover the cost of running the block.

At the luncheon which followed the opening ceremony, the Chairman of the Company, Mr. Ambrose Firth, said they had been encouraged to proceed with the scheme as a result of the success of the "pilot plant" which had been installed at their Newhall works over a year ago. There they had been gratified by the response of the employees; some 65–70% of those eligible were making use of the facilities provided. A further block for 200 men was nearing completion at the foundry of their subsidiary company, Moorwoods, Ltd.

The Institution of Metallurgists

THE Annual General Meeting of the Institution of Metallurgists was held at 4, Grosvenor Gardens, London, on Thursday, June 16th, 1949, with the President, Dr. Maurice Cook in the chair.

After expressing his thanks to the members for his re-election as President, Dr. Cook went on to refer to the progress made by the Institution and to some of its plans for the future. Referring to the membership which, during the past twelve months, had risen from 1,701 to 1,894, Dr. Cook remarked that a membership of that size, reached as it had been, in four years, reflected above all else the keenness of the desire of metallurgists to have such an organisation and, quoting from the Memorandum of Association, "enhance the status and prestige of metallurgists," especially when it was realised that the great majority of applications had been spontaneous. Nevertheless, he believed there were probably some hundreds of metallurgists in the country who were qualified to become members of the Institution in one grade or another and he repeated the appeal he made a year ago for the help of members in encouraging those who might be qualified to seek membership.

Membership was already open to metallurgists in Commonwealth countries and the Council, after the most careful consideration, had now decided, in principle, to admit foreign members and it was hoped that the value and usefulness of the Institution would spread to an ever-widening circle of metallurgists.

It was vitally important that the examinations set for the various grades should be such that their acceptance as worthy standards of qualification was unquestioned, and the thanks of the Institution were due to the Examinations Board for their efforts to that end. In the first year in which the examinations were held, 1947, there were 19 candidates, last year the number was 54 and this year, although the closing date had not been reached the number of applicants had risen to 85. To date examinations had only been held in this country, but there were a number of candidates from abroad who would like to take them in their own countries. In that connection, there had been encouraging offers of assistance from a number of University and College Authorities in Canada, South Africa, Australia and New Zealand, which was most gratifying, pointing as it did to the widespread interest in and support for the Institution. It was likely that examinations in some centres abroad would be held in 1950. Whilst on the subject of examinations, Dr. Cook mentioned that the Ministry of Labour and National Service had agreed to grant under certain circumstances, deferment from National Service, to *bona fide* candidates for the Licentiateship of the Institution.

As Refresher Courses continued to be a very popular feature of the Institutions activities, and as the two already held were acclaimed on all sides as unqualified successes, arrangements had been made for a third to be held at Ashorme Hill from September 16th to 18th. The programme which included six lectures on the various aspects of " The Fracture of Metals " had been finalised and all arrangements for the meeting completed.

As perhaps the best and most effective way of engaging the interested attention of the general public in metallurgy, the Council had decided to hold an exhibition entitled " Metals in the Service of Mankind " which, by courtesy of the Director, would be housed in the Science Museum, South Kensington. It was expected that it would be open from the beginning of July to the end of September, 1950. In addition to being open to the general public, facilities would be provided for organised parties of students, from schools and colleges in London and the provinces, to visit the Exhibition, the aims of which were, in brief, propaganda and education. The Services and Publicity Committee were dealing with the matter for the Council and the working party which they had appointed had been very active in planning and arranging the project. The offers of help, especially in the form of exhibits, were most heartening and augured well for its success.

Resistance Welding Machines

IN reviewing the past year's activities of the resistance welding machine industry at the recent annual meeting of this section of the British Electrical and Allied Manufacturers Association, Mr. R. W. Ayers, chairman, said that expansion had continued in home and export sales, order books are extremely healthy, and the engineering industry is turning more to resistance welding as a process to cut manufacturing costs and improve production wherever metal products are fabricated. In common with other industries, he said, we are finding export selling is getting more difficult, and as an Association we will need to give increasing attention to developing export trade.

An important part of the work of the Association is to maintain close working relations with the main Departments of the Board of Trade, Ministry of Supply and other Government Departments, as well as with trade and professional associations and institutes concerned with engineering. With the greatly increased activities of the Government in detailed industrial affairs it has become of great importance that Trade Associations, competent to speak for the industries they represent, shall work closely with the Government in planning or control, since the men responsible for implementing the Government's policy cannot be expected to have detailed knowledge of business affairs.

Work with the newly formed British Electricity Authority is proving important ; this body gave its assent to the publication of the Memorandum on Welding Load, which was distributed in the early part of 1949 to supply engineers at home and abroad, and it is noticeable that many B.E.A. Area Boards have ordered quantities for distribution to their staffs.

Technical and Production Committee

With the increased interest of other technical and professional bodies in welding matters which has developed over the past few years, this Committee seldom has need to initiate or undertake specific programmes of technical or research work, excepting *ad hoc* problems concerned directly with machines or applications. Its function has become increasingly to appoint members to other Committees, and to review their work and publications, so that the interests of members are protected wherever Committees are considering matters in which resistance welding plays a part. Work of this nature is at present centred in the British Standards Institute, the British Welding Research Association, the Institute of Welding, and to a lesser extent in the newly formed International Institute of Welding.

Staff Changes and Appointments

Duncan Stewart and Company Limited, one of the Davy-United Group of Companies, have appointed as their new Assistant General Manager, MR. K. S. ARNOLD, B.Sc., M.I.Mech.E., Assoc. I.E.E. Mr. Arnold also becomes a Director of this well-known Glasgow Company, which in addition to hydraulic and steelworks plant engineering specialises in the production of sugar machinery.

MR. I. A. R. STEDEFORD, Chairman and Managing-Director of Tube Investments Limited, left Britain by air for India on July 3rd, 1949. During his stay he will visit Delhi, Bombay and Madras, and will be conferring with Indian industrialists and merchants on plans of mutual interest. He is accompanied by a director of Tube Investments, MR. ARTHUR CHAMBERLAIN.

MR. B. W. SILVERWOOD has recently been appointed Technical Commercial Welding Engineer to the Industrial Department of Philips Electrical Ltd. Mr. Silverwood has previously been associated with the organisation of training courses in Arc Welding with Sir William Arrol and Co., Ltd., Alloa, and the Quasi-Arc Co., Ltd.

At the annual general meeting of the Resistance Welding Machine Manufacturers' Section of B.E.A.M.A., MR. R. W. AYERS (Managing Director Sciaky Electric Welding Machines, Ltd., Slough, Bucks) was elected Chairman for the year 1949/50, MR. F. SIMMONS (British Federal Welder and Machine Co., Ltd., Dudley, Worcs.) was elected Deputy-Chairman and MR. E. S. WADDINGTON (Philips Industrial, Ltd., London) Vice-Chairman.

At the twenty-fourth annual general meeting of Electroflo Meters Co., Ltd., industrial instrument manufacturers, of Park Royal, London, and Maryport, Cumberland, held on June 1st, 1949, MR. H. R. WALTON, B.Sc (Technical Sales Manager) and MR. L. E. MEEKS (Works Manager) were appointed to the Board of Directors. Mr. G. H. BARKER, A.M.I.E.E. (Sales Director) was appointed joint Managing Director with Mr. B. DUNGLINSON, F.Inst.F., the Chairman and Managing Director of the Company.

MR. ERIC BROTHERTON has been appointed Joint-Managing Director of the Tube Investments subsidiary, The Hercules Cycle and Motor Co., Ltd.

MR. A. D. STORKE, C.M.G., has resigned his appointment as Director of Climax Molybdenum Company of Europe, Ltd., London and Sheffield, as from June 30th, 1949.

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

AMPEROMETRIC TITRATION

Part IV—Some Preliminary Experiments on the use of 8-Hydroxyquinoline

By J. T. Stock

(Chemistry Department, L.C.C. Norwood Technical College, Knight's Hill, London, S.E.27)

By use of small cells, milligram- and microgram-quantities of copper, zinc, and cadmium may be titrated amperometrically with 8-hydroxyquinoline solution. In the case of copper, the titration curve retains its shape when the metal concentration is as little as 1×10^{-4} M. The low solubility of its complex permits the titration of copper in the presence of cadmium. In the presence of zinc, however, co-precipitation occurs, as it does in the titration of zinc-cadmium mixtures.

PREVIOUS parts in the series[1] have dealt with the general principles involved in amperometric titration, the apparatus used, and titration with special reference to the rotating platinum micro-electrode as indicator. Since the appearance of these articles, the author has had occasion to examine polarographically several quinoline derivatives which are of utility in the gravimetric determination of metals. This in turn led to an investigation of the possibilities of these derivatives in the amperometric titration of milligram- and microgram-quantities of metals. The work on quinaldinic acid and quinoline-8-carboxylic acid is in the course of publication,[2] and the present article deals with some preliminary experiments (which are now being extended) on the use of 8-hydroxyquinoline in this connection.

Organic Reagents in Amperometric Titration

Possibly owing to its ready availability, 8-hydroxyquinoline was one of the first selective organic reagents for metals to be employed in the technique of amperometric titration. Salicylaldoxime,[3] and dimethylglyoxime,[4] appear to be the only reagents of this type that pre-date it. In 1940, Zan'ko[5] showed that 8-hydroxyquinoline could be used for the amperometric titration of zinc, copper, magnesium, and aluminium, the former two metals being determined in a buffered acetate solution, while an ammonia—ammonium chloride buffer was recommended in the case of magnesium. For aluminium, either ammoniacal or acetic acid medium could be used. The author has been unable to inspect the original paper (and would be grateful for any news of the availability of a copy !), but it is fairly clear from published abstracts that the work was concerned with other than highly-dilute solutions. For example, dissolved oxygen (not "hydrogen," as stated in both German and American abstracts) was not removed from the solution, the oxygen diffusion current being compensated. Although doubtless practicable when the oxygen: substance-to-be-determined ratio is small, it is the author's experience that trouble is encountered when the ratio is otherwise.

In the same year, Gillis, Eeckhout, and Standaert used 8-hydroxyquinoline for the amperometric titration of bismuth, using an applied voltage of –0·85 and a tartrate-acetate-acetic acid supporting solution.[6] Here again, the original paper is not available, but it is clear that fairly high concentrations of metal were involved. The abstracts make no mention of the deoxygenation of the solution. Maxima are suppressed by adding 50 drops of 0·1% phenolphthalein solution to a sample having a total volume of some 20 ml. Since the potential of the dropping mercury electrode with respect to, say, the saturated calomel electrode and the exact pH conditions are not known, it is difficult to say whether or no this maximum-suppressor was itself contributing to the total current. The half wave potential—pH relationships of phenolphthalein recently determined by Kolthoff and Lehmicke[7] do, however, indicate this possibility.

The imposing bibliography of the applications of 8-hydroxyquinoline in the determination of metals[8] is indicative not only of the utility of this reagent, but also of its lack of selectivity. Accordingly, these preliminary investigations were confined to the titration of copper and of cadmium, and to the effect of the presence of zinc on the results.

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[1] Stock, J. T., *Metallurgia*, 1944, **30**, 221, 277 ; 1947, **36**, 51.
[2] Stock, J. T., *J.C.S.*, in the press.
[3] Neuberger, A., *Arch. Eisenhüttenw.*, 1939, **13**, 171.
[4] Neuberger, A., *Z. anal. Chem.*, 1939, **116**, 1.
[5] Zan'ko, A. M., *Dopovidi Akad. Nauk. U.S.S.R.*, 1940, No. 6, 27, 32 ; *Chem. Zentr.*, 1942, II, 1606.
[6] Gillis, J., Eeckhout, J., and Standaert, G., *Meded. Kon. Vlaamsche Acad. Wetensch., Letteren Schoone Kunsten België, Klasse Wetensch.*, 1940, No. 7, 3 ; *Chem. Zentr.*, 1942, II, 202.
[7] Kolthoff, I. M., and Lehmicke, D. J., *J. Amer. Chem. Soc.*, 1948, **70**, 1879.
[8] See, for example, "Organic Reagents for Metals," Hopkin & Williams, Ltd., 4th Edn., London, 1943, pp. 86–97.

Experimental Arrangements

Stock solutions of the three metallic ions were prepared from B.D.H. " AnalaR " sulphates and were standardised gravimetrically by precipitation with quinaldinic acid[9]. The solutions were diluted as required with the appropriate supporting solutions and sufficient 1% gelatin solution to render 0·03% with respect to this substance. Unless otherwise specified, the supporting solutions were hydrochloric acid—acetate mixtures which were 0·2 M with respect to sodium acetate. Reagent solutions in 50% aldehyde-free ethanol were prepared from an " AnalaR " sample that had been twice recrystallised from aqueous ethanol and dried over sulphuric acid.

Samples of from 5–10 ml. were titrated in a cell made from a boiling tube,[10] while those having a volume of about 1 ml. were handled in an all-glass micro-cell.[11] In both instances, a mercury pool anode was used. The applied voltage was adjusted by means of a polarising unit constructed mainly from radio parts.[12] In this was incorporated a damping control for the calibrated Cambridge " Spot " galvanometer used to measure the current flowing through the cell. Before titration, the solution in the cell was thoroughly deoxygenated with a stream of nitrogen, and the gas stream was bubbled through the solution for 3 minutes after each addition of reagent.

Titration of Copper

In their work on the gravimetric determination of metals with 8-hydroxyquinoline, Fleck and Ward[13] showed that the lowest permissible pH for complete precipitation of copper is 5·33. Experiments were accordingly initiated at a somewhat higher value, viz., pH 6·0. With an applied voltage (E$_a$) of –0·4, at which copper, but not 8-hydroxyquinoline, yields a reduction wave,[14] progressive addition of the reagent should cause the current to fall to a small value near the end point and then to remain sensibly constant with further addition of reagent. Curves of this type, some of which are shown in Fig. 1, were actually obtained. (In all cases, the observed current was corrected for the diluting effect of the added reagent).[15] At ordinary temperature, precipitation is rapid, even when the reagent concentration is 5×10^{-3} M. Typical results are given in Table I.

TABLE I.—TITRATION OF COPPER WITH 8-HYDROXYQUINOLINE SOLUTION

Temp. = 11 – 15° ; E$_a$ = –0·4 volt. Interval between additions, 3–4 min.

Vol. of Sample, ml	Supporting Solution	Concentrations, $\times 10^{-3}$ M.		Titres, ml	
		Copper	Reagent	Theor.	Obsd.
10	Acetate, pH 6	2·5	10	5·00	5·02, 4·96
1	" "	1·75	5	0·700	0·700
1	" "	1·26	5	0·504	0·501, 0·502
1	" "	0·75	5	0·300	0·300, 0·303
1	" "	0·25	5	0·100	0·100
1	Tartrate	1·75	5	0·700	0·699
1	"	0·75	5	0·300	0·300, 0·298

The smallness of the current flowing after the end point has been passed and the almost complete absence of rounding of the curves in the region of the end point indicate the very low solubility of the copper complex under the experimental conditions. These features persist at extremely high dilutions. By way of example, a typical titration curve obtained by titrating with 1×10^{-3} M 8-hydroxyquinoline solution 1 ml. of a solution which was only 1×10^{-4} M with respect to copper is shown in Fig. 2. Under these somewhat extreme conditions, results have so far been some 5% low, but " ageing " the cell and cutting down or eliminating the gelatin have given encouraging signs.

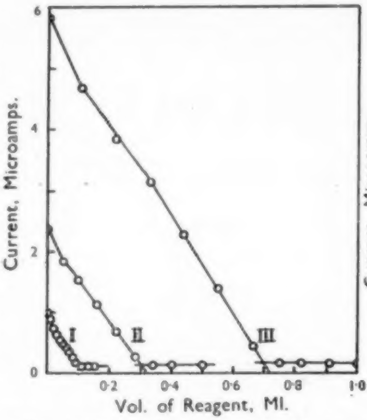

Fig. 1.—Titration of 1 ml. of copper solution with 5×10^{-3} M oxine solution. Copper concentrations, $\times 10^{-3}$ M :— Curve I, 0.25 ; II, 0.75 ; III, 1.75.

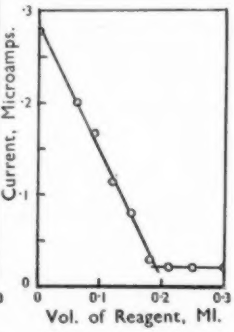

Fig. 2.—Titration of 1 ml. of 1×10^{-4} M copper solution

The other peculiarity of the curves (Fig. 1) is the abrupt fall in the current which occurs on the first addition of reagent. This may be due to entrainment, then subsequent release, of copper by the precipitate. Fortunately, however, the major portion of the descending arm of the titration curve is linear. In 0·07 N sodium potassium tartrate supporting solution, on the other hand, the fall in current is less in the early stages of the titration than expected. This effect is, however, not uncommon in the amperometric titration of dilute solutions, e.g., of nickel by dimethylglyoxime.[16] The titration curves of copper in tartrate medium are sharply-defined at the end point, like those obtained at pH 6·0.

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[9] Rây, P., and Bose, M. K., *Z. anal. Chem.*, 1933, **95**, 400.

[10] Stock, J. T., in " Methods of Quantitative Micro-Analysis," ed. Milton and Waters, Arnold, London, 1949, p. 479 ; see also *Analyst*, 1944, **69**, 178.

[11] Stock, J. T., *op. cit.*, p. 477 ; see also *Analyst*, 1946, **71**, 583.

[12] Stock, J. T., *Analyst*, 1946, **71**, 585.

[13] Fleck, H. R., and Ward, A. M., *Analyst*, 1933, **58**, 388.

[14] Stock, J. T., *J.C.S.*, 1949, 586.

[15] Kolthoff, I. M., and Lingane, J. J., " Polarography," Interscience Publishers, Inc., New York, 1941, p. 450.

[16] Kolthoff, I. M., and Langer, A., *J. Amer. Chem. Soc.*, 1940, **62**, 211 ; Kolthoff, I. M., and Lingane, J. J., *op. cit.*, p. 470.

(*To be continued*)

Miscellaneous Michrochemical Devices XIX—An Adjustable Support for Light Apparatus

By J. T. Stock and M. A. Fill

(*L.C.C. Norwood Technical College, London, S.E.*27

USED in conjunction with the clamp previously described,[1] the adjustable support shown in Fig. 1 has been found to be very useful in assembling or exhibiting microchemical apparatus. No metal is used in the construction so that troubles due to corrosion do not occur.

Upright A is a length of 2 mm. diameter glass rod bent to hairpin form and then into a base B as shown. The gap between the arms of the upright should be

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[1] Stock, J. T. and Fill, M. A. *Metallurgia*, 1947, **35**, 172.

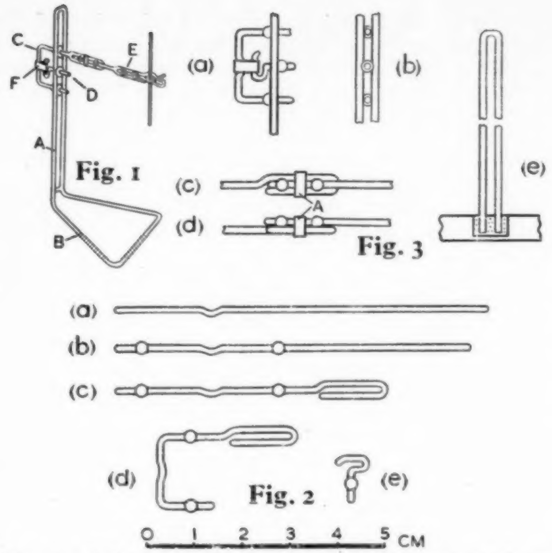

Fig. 1.—Adjustable support and clamp constructed from glass rod.
Fig. 2.—Stages in the construction of the slider and clip.
Fig. 3.—Assembly of parts.

2·5 to 3 mm. A small glass bridge is added to confer rigidity. Slider C, clip D and clamp E are also of 2 mm. diameter glass rod. Gripping force is provided by the small strong rubber band F (cut from good quality thin walled rubber tubing). To adjust the height of the slider on the upright, the gripping force is relieved by squeezing together the parallel walls of the band with the thumb and forefinger applied either side of the rear of the slider. The clip is thereby forced slightly forward and the unit comprising the slider, clip, and rubber band may then be slid freely up and down.

Details of the construction of the slider are shown at (a), (b), (c) and (d) in Fig. 2. The spheres should be 4 to 5 mm. in diameter and should be formed by working in a small hot flame so that thickening up does not occur beyond the limits of the sphere; otherwise wedging on the upright is likely. Details of the clip are shown at (e). To assemble, the rubber band is placed on the slider, and the latter is inserted from the rear of the upright as shown at (a) in Fig. 3. The clip is now inserted from the front and the band is sprung into position. A front elevation is shown at (b). The stem of a glass clamp of suitable size, constructed as previously described,[1] is modified by having two spheres formed upon it. These serve to locate the stem in the "hairpin" at the extremity of the slider, as shown in plan and elevation at (c) and (d) respectively. Retention is by a band A cut from rubber tubing. This arrangement allows the clamp to be rotated about a horizontal axis and to be slid backwards and forwards.

An alternative arrangement of the upright is shown at (e), Fig 3. Instead of using a glass rod base, the ends of the upright are secured by sealing wax in a recess bored in a block of wood, taking care that the latter is perpendicular to the upright.

This device may be made in other sizes by using glass rod of appropriate diameter.

Quantitative Inorganic Paper Chromatography

Sub-micro Separation and Determination of Aluminium, Iron and Titanium*

By A. Lacourt, G. Sommereyns, E. Degeyndt, J. Barugh and J. Gillard

(*Microchemistry Department, Université Libre de Bruxelles, 50, Avenue F.-D. Roosevelt, Brussels*)

PAPER chromatography of cations and anions in aqueous solution has only recently been investigated,[1] quantitative results having been achieved by Linstead and his co-workers, who have already published some very important contributions to the subject.

The work here described began in 1946. It appeared that organic solvents behave in a similar way, in inorganic paper chromatography, to that found in organic paper work. The adsorbed salt spot gives rise to a chromatogram whose nature depends on the cation and anion of the salt, the pH of the solution, and the nature and pH of the solvent used for development. Changes in the composition of the solvent are likely to alter the chromatogram, just as in the case of organic chromatography.[2]

So far our experiments have dealt with iron, titanium and aluminium chlorides, and cobalt and nickel chlorides and nitrates. We have used downward development.

The salt solution, containing from 1–10 micrograms of salt, is drawn directly from a horizontal capillary burette which delivers 0·01 ml. with an accuracy of ± 0·0002 ml. It is deposited at the usual place, 3·5 cms. from the top of a strip of Whatman No. 1 filter paper. The following general effects have been noted. So far, only solvents miscible with water have given satisfactory separations, though other solvents may ultimately prove on investigation to be useful. Pure ether oxides do not produce a separation. Dioxan, in the dark, carries iron along the liquid front. Alcohols show decreasing development with increasing molecular weight, whereas aliphatic acids (formic and acetic) show the reverse effect. Acetone also carries iron on the liquid front.

Acid salt solutions produce different chromatograms from the neutral solutions, even if the solution spot is dried before development. This indicates some form of interference from the paper. Another indication of this effect is that a developing solvent which has an acid concentration equivalent to that of the salt solution also gives a different result.

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* Read at the Belfast Meeting of the Microchemistry Groups, May 10th, 1949. This research was subsidised by the Belgian I.R.S.I.A.

[1] Lederer, H., *Anal. Chim. Act*, 1948, **2**, 261; *Nature*, 1948, **162**, 776; Linstead, R. P., *et al.*, *Nature*, 1948, **162**, 691.

Chlorides and nitrates often give different results, the chlorides being preferable for separations.

Mixed solvents such as pyridine-acetone, pyridine-methanol, pyridine-water, in varying proportions, are good developing agents for the cations which we have investigated, giving sharp, well-defined spots in, for example, the separation of iron from titanium, aluminium and vanadium. Formic acid-ethanol has also proved successful. Addition of dry or concentrated hydrochloric acid or ammonia to a solvent may improve the sharpness of the spots. For example, addition of 1% HCl to an acetone-ethanol mixture (95 : 5) brings about a very good separation of cobalt from nickel, cobalt lying on the liquid front, whereas in the absence of acid no separation occurs. Diluted formic acid (6N) can also be used in the quantitative separation of aluminium from titanium and iron. These separations take no more than 30–60 minutes.

It is of importance that small variations in the composition of a solvent may cause an appreciable difference in the chromatogram. In consequence, impurities in solvents may be detected. Thus pure dioxan gives a very sharp liquid front concentration of iron, whereas when this solvent contains peroxide, iron spots are dispersed, and as little as 2% of peroxide will produce a perceptible effect. Variation of the composition of a pyridine-water mixture may cause alteration of the order in the iron-titanium-aluminium chromatogram. Further study of mixed solvents in inorganic chromatography will undoubtedly produce results of value.

Qualitative use

For qualitative purposes, the paper strip bearing the spots is dried after development, and is then sprayed with the appropriate reagent solution, or kept for a time in an atmosphere of gaseous reagent such as ammonia or sulphuretted hydrogen.

Quantitative estimation

Such a procedure is not necessary for quantitative purposes. The ratio between the distance of travel of the ion and the distance of travel of the liquid front is characteristic for each ion in any given set of experimental conditions. Consequently measurements on a test strip will serve as a guide to the location of the ion-spots on a strip which has not been treated with reagent solutions.

Examples are given in Table I.

TABLE I

	Iron	Titanium	Aluminium	Liquid Front
Strip A, mm.	80	72	100	100
Strip B, mm.	91	92	106	106

Having obtained the measurements on a test strip, it is then possible to cut any dried strip, and to elute the portions prior to quantitative determination of the separated ions.

It is clear from the data in Table I that the method can be used to separate aluminium from titanium and iron. These results were obtained using an acid solution (pH 0·7). Developing with 6N formic acid, the method can be applied to amounts of 5–10 micrograms contained in 0·01 ml. of solution. After 60 minutes of development at 20° C., aluminium lies on the liquid front, the other two elements lying some distance above this. Drying and cutting could easily be done at this stage, but a still more efficient separation is possible. By treating with air saturated with water vapour (17·5 mm. at 20° C.) a downward migration of the aluminium occurs, and after a further 100–135 minutes the bottom of the aluminium spot is now about 40 mm. below the initial liquid front, while the iron-titanium spot still remains above it. The paper is now dried and cut at the initial liquid front, and aluminium is quantitatively eluted by soaking for 40 minutes in 2 mls. of water at 80° C. It is of interest to note that it is not possible to elute the aluminium satisfactorily with acid solutions, thus supporting the view that the paper interferes in the process.

Elution with sulphuric acid, 0·25%, hydrochloric acid, 0·5%, or a mixed solution containing 1–2% hydrochloric acid and 5–7% acetic acid brings the iron and titanium into solution. Even better elution can be achieved by siphoning a 0·5% hydrochloric-acid solution through the paper strip for 90 minutes, according to Martin's technique.

Spectrophotometric determination of aluminium by aluminon (pH 4.7, λ520 mμ.) gave the following results :

10 μg. aluminium : Found, 10·0, 9·8, 10·1, 9·7, 10·1, 10·2 μg.

9 μg. aluminium : Found, 8·8, 9·0, 9·3, 9·4, 9·4, 9·4 μg.

Iron and titanium are determined in the single solution by tiron.[3]

(Iron, pH 4·7, λ560 mμ. Titanium, pH 4·7, λ410 mμ).

10 μg. iron : Found, 10·3, 10·3, 10·0, 10·0 μg.

10 μg. titanium : Found, 10·3, 9·8, 9·9, 9·6 μg.

Since the formic acid procedure involves the additional capillary migration of the aluminium, the determination is rather longer than if only solvent development were used. However, a large number of determinations can be run concurrently, and the spectrophotometric estimation of the aluminium can be carried out during the elution of the iron-titanium spots. It is hoped that use of a developing solvent which does not necessitate a migration technique for aluminium will enable us to achieve the whole quantitative procedure, including the initial chromatography, in 3 hours.

Work on the quantitative separation of nickel and cobalt, and investigation of the behaviour of other cations and anions are in progress.

We are indebted to the Belgian I. R. S. I.-A. for financial assistance which has provided us with the necessary apparatus for measurement, and we take this opportunity of expressing our gratitude to the Directors of the Institution.

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[2] Strain, *Ind. Eng. Chem., Anal. Ed.*, 1946, 604.

[3] Yoe and James, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 111 ; Yoe and Armstrong, *ibid.* ,1947, **19**, 100.

Institute of Welding

Mr. O. V. S. Bulleid, C.B.E., M.I.Mech.E., has been elected President of the Institute of Welding for the year 1949/50, and Mr. C. S. Milne Vice-President.

Mr. Bulleid, who is about to retire from his present post as Chief Mechanical Engineer, British Railways Southern Region, has been appointed Consulting Mechanical Engineer to Coras Iompair Eireann (Irish Transport Company). Mr. Milne is founder and head of the firm of C. S. Milne and Co., Ltd., Deptford.

The address of the London office of Dr. R. Genders, M.B.E., D.Met., F.R.I.C., F.I.M., Consultant Metallurgist, is now 20, Buckingham Gate, London, S.W.1. Telephone : Victoria 6581.

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"Speedicut" H.S.S. and "Die-Hard" Tungsten Alloy Steel Hacksaw Blades.
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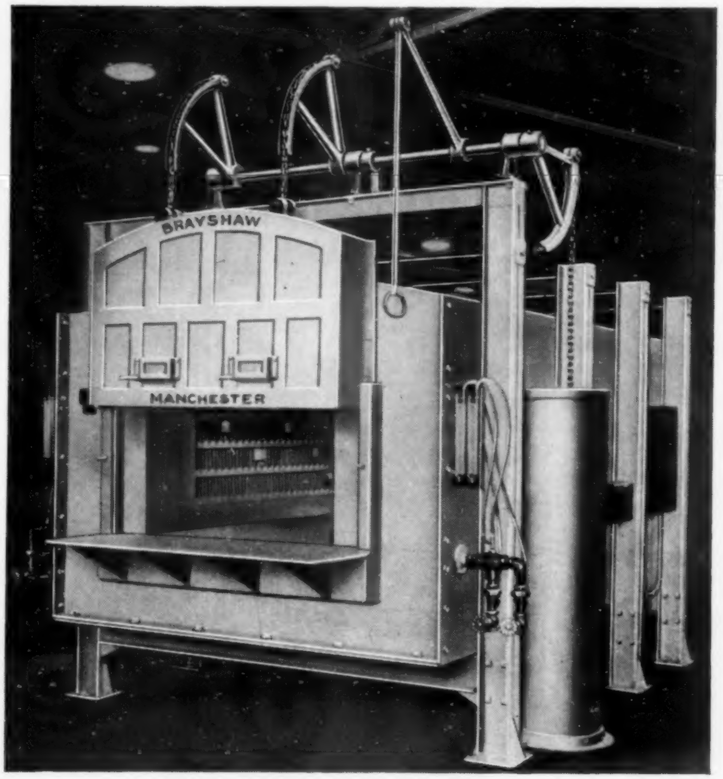
"Hardometer" Hardness Testing Machine.
Twist Drill Point Sharpening Machine.
"Crypto-Atlas" Bandsawing Machine and Bands.
"Mitia" Carbide Saw-Sharpening Machine.



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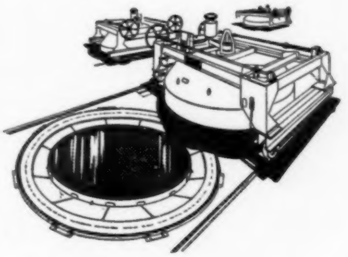

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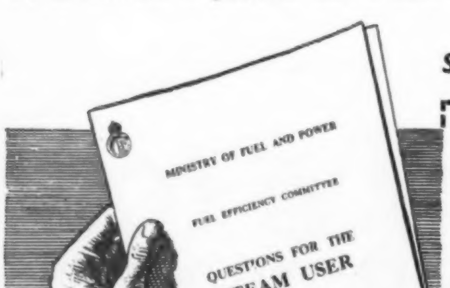
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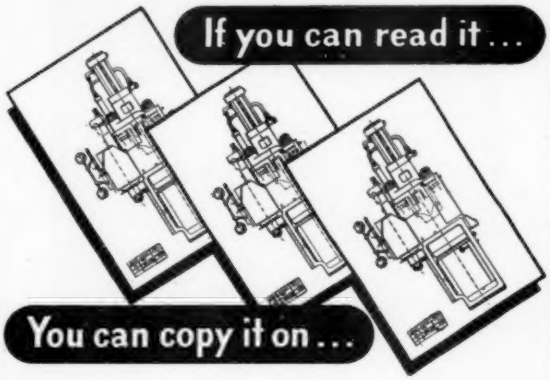
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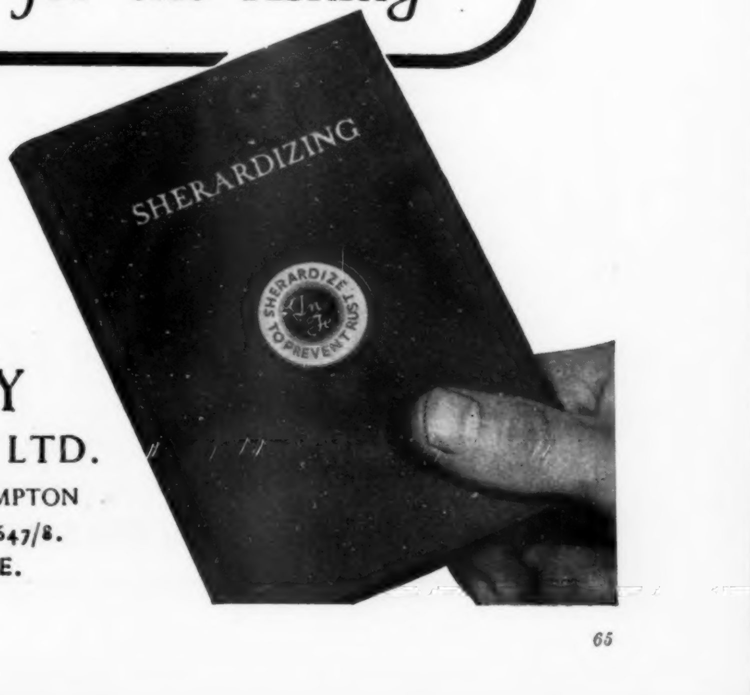

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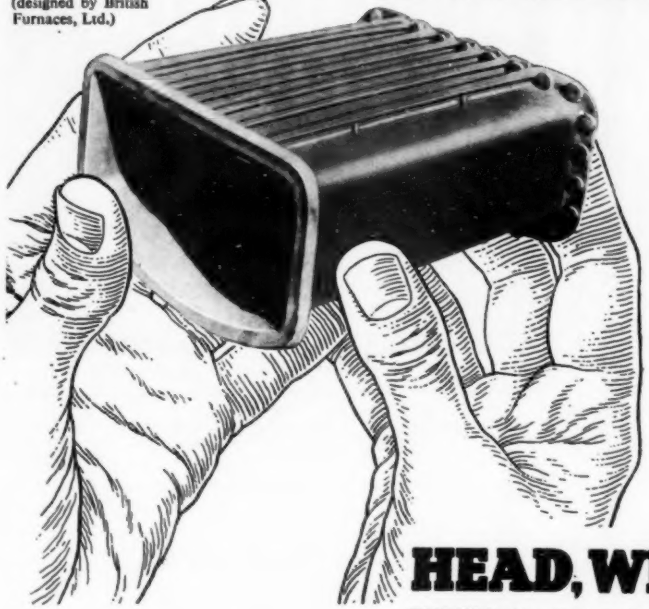

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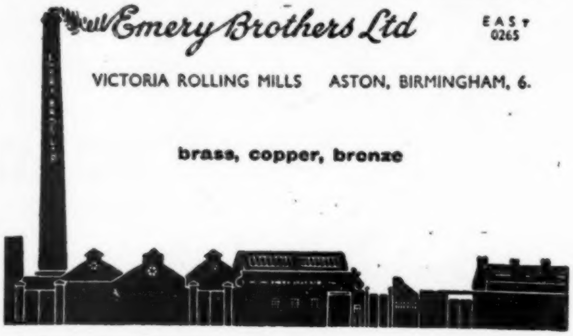

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It may be paternal pride

but to us

these parts

are greater

than

this whole

The instruments that reproduce sound and sight — radio sets, radiograms, gramophones and television sets — owe a great deal to zinc alloy die casting. This pick-up arm and its head* are good examples of the process as an ingenious designer can use it.

Why the parts are zinc alloy die cast

The forepart of the arm is hollow and carefully balanced by the solid metal at the other end so that the needle touches the record with exactly the right pressure. This not only reduces friction but improves reproduction. Zinc alloy pressure die casting enables the dimensional accuracy and stability demanded by such precise balance to be repeated quickly and economically in casting after casting.

Like so many other zinc alloy components, the arm and head are chromium plated: a fact which explains why any number of zinc alloy die castings go through life unhonoured and unsung because unrecognized!

Other sound-reproduction uses

Zinc alloy die castings also play a large part in record changing mechanisms, radio and television chassis, cabinet parts, sound boxes and many other kindred components.

Some facts about zinc alloy die casting

Speed of production is an outstanding feature of the die casting process — the shortest distance between raw material and finished product. Zinc alloys are the most widely used of all metals for die casting because they yield castings with the following qualities:

STRENGTH: Good mechanical properties for stressed components.

ACCURACY: Castings can be made practically to finished dimensions and need little or no machining.

STABILITY: Close tolerances are maintained throughout the life of the casting.

These are the properties which accounted for the widespread wartime use of zinc alloy die casting in the quantity production of such things as fuses, gun sights, periscopes and tank carburettors.

British Standard 1004

Alloys conforming to B.S.1004 should be specified for all applications where strength, accuracy and stability are essential.

ZADCA

ZINC ALLOY DIE CASTERS ASSOCIATION
LINCOLN HOUSE, TURL ST., OXFORD.
TELEPHONE: OXFORD 48088

ZINC ALLOY DIE CASTINGS PLAY AN IMPORTANT PART IN THE EXPORT MARKET

Enquiries about the uses of zinc alloy die casting are welcome. Publications and a list of Members will be sent on request.

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* Photograph reproduced by courtesy of Collaro Ltd.

Reduced Machining Allowance

Where normally economies in machining are difficult to maintain by reason of excess surface material, HOLFOS (Regd.) BRONZE cored bars manufactured by the SPUNCAST centrifugal process have now proved a positive advantage.

Machining allowances can be safely reduced to a minimum by this accurately cast high quality Bronze, and we shall welcome the opportunity of making recommendations to enable you to have the benefit of material saving where this is possible.

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